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# Scientific Results

OF THE

# Katmai Expeditions

OF THE NATIONAL GEOGRAPHIC SOCIETY. I–X.

BY

ROBERT F. GRIGGS,
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and
JAMES S. HINE,
*Sometime Members of the Ohio State University*

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# PREFACE.

Although the Katmai Expeditions have been initiated and financed exclusively by the National Geographic Society, the personnel of the expeditions has been made up, from the first, largely of Ohio State men, and the Scientific Results have to a large extent been worked up in the laboratories of the University. It seems appropriate, therefore, that these results should be issued among the contributions from the Ohio State University.

These papers were first published in the *Ohio Journal of Science.* They are here reprinted without change other than the correction of a few typographical errors which were serious enough to be misleading. It is expected to continue the publication by issuing further papers as they are prepared. When the series is complete it is planned to revise them and to bring them together in book form as a single publication by the National Geographic Society.

R. F. G.

## CONTENTS.

SCIENTIFIC RESULTS OF THE KATMAI EXPEDITIONS OF THE NATIONAL GEOGRAPHIC SOCIETY.

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# I. THE RECOVERY OF VEGETATION AT KODIAK.*

ROBERT F. GRIGGS.

## PREFATORY NOTE.

When its magnitude is fully understood by the scientific world, the eruption of Katmai is certain to rank with that of Krakatoa as a unique exhibition of the forces of vulcanism. To the National Geographic Society alone belongs the credit of having made known to the world this tremendous eruption. As soon as the news came that there had been a great volcanic explosion in Alaska, the society dispatched Dr. Geo. C. Martin to the scene. His report published in the National Geographic Magazine for February, 1913, remains the only detailed record of the events of the eruption. This first study was followed up by three other expeditions under the direction of the writer, whose results have been summarized in the National Geographic Magazine for January, 1917 and February, 1918.

The purpose of the society in sending these expeditions was, however, quite as much to undertake detailed study of the numerous scientific problems raised by the eruption as to furnish its members with authentic accounts of one of the greatest volcanic disturbances in history. Hand in hand with exploration of interest to all of the 750,000 members of the society, has always gone intensive study of numerous scientific problems which would appeal to a more restricted audience. The Board of Managers of the society has from the first recognized that the expeditions would fail in their purpose if they brought back nothing beyond material for articles suitable for a magazine of general interest to all intelligent people. These articles are, to be sure, as accurate and as truly contributions to knowledge as the most recondite memoir. But it is recognized that they must be brief epitomes in which the detailed data essential to the progress of science must be cut out on account of the limitations of space.

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The expeditions of 1915-1916 owed their inception to the foresight of Mr. Frederick V. Coville, of the Board of Managers, who first recognized the unique opportunity presented by the revegetation of the ash for the solution of many problems of great importance to agriculture connected with the transformation of the raw mineral ash into a humous soil. It was primarily for the study of these problems that the project was undertaken, for no one at that time suspected the existence of the volcanic wonders which were to prove of wider general interest than the specific objective of the expeditions.

Although it has been the intention of the society to provide for the comprehensive study of all the scientific problems growing out of the eruptions, the members of the expeditions have been able to realize this ideal only in part. The scientific problems presented in this remarkable district are so manifold that it has always been necessary to forego the study of many important aspects of the eruption. The eruption was, moreover, so vast a cataclysm that its comprehension passes the power of the human mind. The members of the expeditions have always felt that the results attained were to be measured only by their own limitations of vision and of strength for following up the opportunities that lay around them on every hand.

Good progress has, however, been made along a number of major lines, including the botany of the region; its revegetation so far as that has progressed; the geology of the volcanic district; studies of the volcanic phenomena in some detail; the chemical condition of the ash plains in relation to their colonization by plants; chemical and thermometric examinations of the volcanic emanations in co-operation with the Geophysical Laboratory of the Carnegie Institution; the zoology of the district, the insects especially having received attention thus far; while beginnings have been made in the study of the soil bacteriology and mycology of the devastated areas.

For various reasons the publication of the papers embodying the results of these investigations has been somewhat delayed, but it is now proposed to issue, as rapidly as possible, a series of contributions of which this is the first, making known the results which have been obtained. Inasmuch as the National Geographic Society has no organ of its own suitable for such

papers, the Ohio Journal of Science has undertaken the publication under an agreement whereby the Geographic Society assumes the major share of the expense.

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The eruption of Katmai and its effects on vegetation have been discussed in previous papers.[1-2-3] The present paper is presented as a more detailed record than could be given in the general account of the remarkable recovery shown by the plants buried under the ashfall at a great distance from the vent.

### "GREEN KODIAK" TRANSFORMED TO A DESERT.

It will be recalled that although a hundred miles from the Volcano, Kodiak was covered about a foot deep by the fall of ash, which here has the character of fine sand. The effect of this blanket of ash, coming as it did on June 6, just as the plants were putting forth their spring growth, was to strike down all herbaceous growth, giving "Green Kodiak" the appearance of a pine barren, devoid of vegetation except for the trees and bushes which stuck through the ash uninjured. To everyone who visited Kodiak during the first two seasons after the eruption, the damage done to vegetation seemed irreparable.

It was during this period that I first saw Kodiak in June, 1913, almost exactly a year after the eruption. It was indeed a bleak and desolate prospect. Outside the forest the country had the appearance of a desert, whose gray-brown slopes were relieved only here and there by spots of green where some alder or willow stuck through the ashy blanket (see page 4), or on some steep slope where the ash had been washed off. Lupines, fireweeds, and other strong-stemmed perennials had, to be sure, come up through the ash here and there, but they were not abundant enough to have much effect on the landscape. Within the forest the prospect was less desolate because the spruces stood up out of the ash in something like their original condition, but the undergrowth beneath them was gone and

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[1] Rigg, G. B. The Effects of the Katmai Eruption on Marine Vegetation. Science 40 : 509–513. 1914.

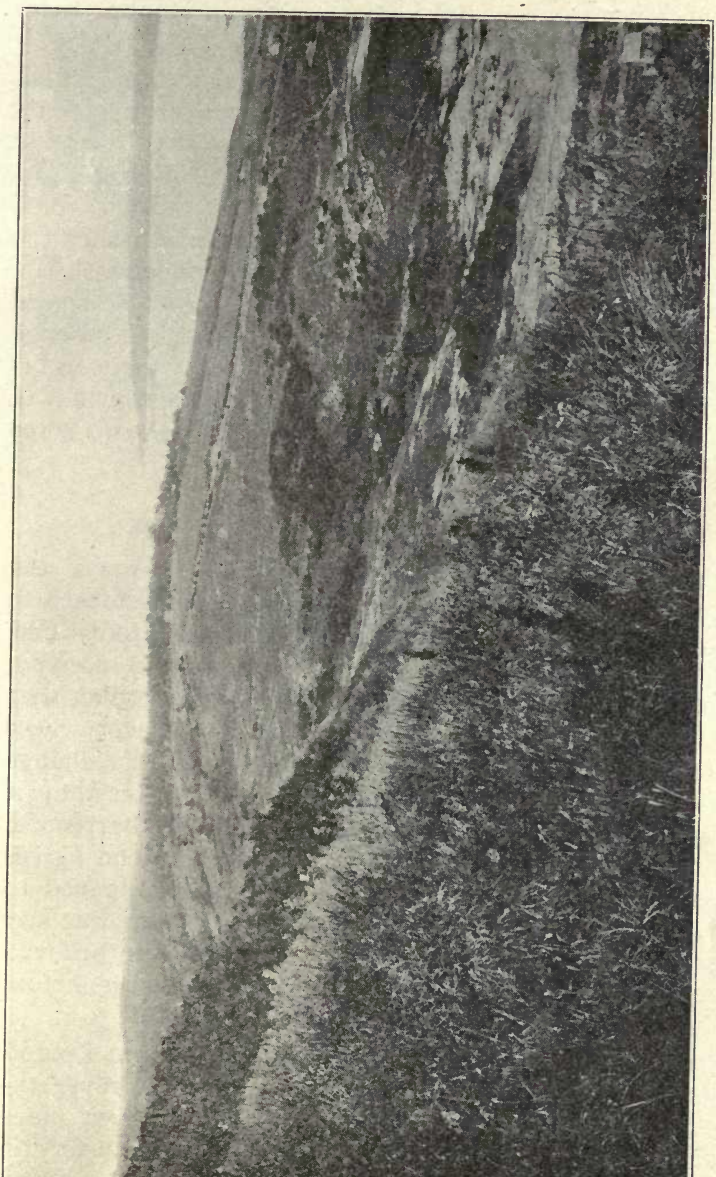
[2] Griggs, Robert F. The Effect of the Eruption of Katmai on Land Vegetation. Bull. Am. Geogr. Soc. 47: 193–203; Figs. 1–10. 1915.

[3] ——, The Eruption of Katmai. Nature 101: 497. 22 Aug., 1918.

*Photograph by M. D. Snodgrass*

ASH COVERED LANDSCAPE NEAR KODIAK.

At the end of the first growing season after the eruption. October 20, 1912.



*Photograph by B. B. Fulton*

THE SAME PLACE THREE YEARS LATER.

Rank grasses have everywhere covered the hillsides coming up from old roots.
The only bare ash yet remaining is in the old swamp at the right.

their branches were still heavily laden with ash, bending them down against the ground (see page 48).

The officials of the Experiment Station and of the Kodiak Baptist Orphanage were attempting to grow a crop of oats to provide ensilage enough to keep their cattle alive over the winter. We felt it our duty to encourage them in this effort, but in reality the prospect seemed very gloomy to us. Well do I remember debating with one of the citizens whether the country would ever come back to its original condition. He, with the vividness of his memory of things as they had been before the eruption, was pessimistic, but I, with the knowledge that the ash would probably be beneficial after it was incorporated with the soil, reassured him with the prediction that in ten years vegetation would begin to come back in some abundance.

## THE MARVELOUS RECOVERY OF VEGETATION.

But during the second and third years the old roots sent up new growth through the ash layer in such profusion as to completely upset even the most optimistic of predictions. When I landed in June 1915, despite the reports I had received, I could not believe my eyes. It was not the same Kodiak that I had left two years before. The mountains were everywhere green with their original verdure. The character of the change is indicated by the pictures on pages 4, 5 and 7 better than it could be by any description. Where before had been barren ash was now rich grass as high as one's head. Everyone agrees that the eruption was "the best thing that ever happened to Kodiak." In the words of our hotel keeper, "Never was any such grass before, so high or so early. No one ever believed that the country could grow so many berries, nor so large, before the ash."

I had come to Kodiak to study the revegetation, but I found my problem vanished in an accomplished fact. The revegetation which I had hoped to study at Kodiak had given place to a remarkable recovery of the antecedent plants, transferring the problem of revegetation proper to the more deeply buried country near the Volcano.

GRASS COME UP THROUGH THE ASH. *Photograph by D. B. Church*

In some places this grass, the native blue top, *Calamagrostis langsdorfii*, penetrated twenty inches of ash. The connection of the present tops with old roots, hold-overs from before the eruption, is everywhere manifest.

## COMPARISONS WITH REVEGETATION IN OTHER VOLCANIC DISTRICTS.

But, although the country around Kodiak presents only a subordinate aspect of the problem of revegetation, it is, as may be seen below, more similar to most of the other volcanic districts whose revegetation has been studied, than the country nearer the volcano. It seems appropriate, therefore, to digress at this point for a comparison of the Katmai district with other volcanic regions.

There is a very natural tendency on the part of many to group the revegetation of all volcanic terrains under a single generalization. Considering how remote volcanic phenomena are from the experience of most botanists, this is quite excusable. But when one's attention is called to the fact that volcanic ejecta not only vary in physical condition all the way from compact glassy rock to fine sand, but also have all the varieties of chemical composition shown by igneous rocks from basic to acid, he sees at once that the establishment of plant life on different volcanic terrains may be as diverse as on soils derived from different varieties of sedimentary rocks. The problems encountered by Forbes[4] and MacCaughey,[5] for example, in studying plant invasion on Hawaian lava flows have little in common with those that confront us in the Katmai district.

Moreover, as our knowledge of the phenomena of the eruption increases, and the affected country is better explored, it becomes more and more evident that the eruption of Katmai stands in a class by itself, offering opportunities for the study of revegetation quite without parallel since the development of modern botany, before which, of course, no such studies could have been made.

### KRAKATOA.

The eruption of Krakatoa, for example, will occur to botanists and geologists alike as the greatest of volcanic explosions. Yet the total area on which the studies of revegetation were made, the island of Krakatoa, was only about five square miles in extent—so small that it could almost be dropped

[4] Forbes, C. N. Prelim. Obs. Concerning the Plant Invasion on Some of the Lava Flows of Mauna Loa, Hawaii, Bishop Mus. Honolulu. Occ. Pap. 5: 15–23. 1912

[5] MacCaughey, Vaughan. Vegetation of Hawaiian Lava Flows. Bot. Gaz. 64: 386–420. 1917.

bodily into the crater of Katmai. In the present case, the area covered by deep deposits, through which the roots of plants can not reach the original soil, is more than a hundred times as large.

Unfortunately, moreover, the study of Krakatoa was of a very fragmentary nature. It was three years after the eruption before the island was visited at all. Revegetation had already begun on an extensive scale[6]. This first plant life consisted of blue-green algæ and ferns, but several species of seed plants were already well established. After this first brief visit no other observations are recorded for eleven years, until 1897 when it was visited by Penzig[7]. After this visit, a similar period elapsed before another visit, that of Ernst[8] and Campbell[9]. Although Ernst has worked up the data gathered, in masterly fashion, it should be remembered that his opportunity for field examination was very brief, consisting of only a few hours, during which time it was not possible so much as to reach the summit of the island, much less to explore it carefully.

These workers, moreover, paid little attention to the problem which most concerns us, namely, the means of preparation of the raw inorganic soil for the life of higher plants, but studied especially the means of dispersal by which the plants reached the new land, making the observations the basis of a study in plant distribution for which Krakatoa, by virtue of its insular position, offered a unique opportunity not duplicated at Katmai.

Since these papers are well known to most botanists, there is no occasion to abstract them at length here. Probably the most significant of the results brought out are the following: (1). The pioneer vegetation consisted not of flowering plants, but of Blue-green algæ (Cyanophyceæ), which were followed by ferns and then by flowering plants. (2). The first flowering plants were species whose seed was either distributed by the wind or by ocean currents, invasion progressing largely from the strand. (3). It was believed that the nitrogen compounds necessary for the growth of the luxuriant vegetation were

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[6] Treub, M. Notice sui la nouvelle Flore de Krakatau. Ann. Jard. Bot. Buitenzorg 7: 213–223. 1888.

[7] Penzig, O. Die Fortschnitte der Flora des Krakatau. Ibid 21 : 92–113. 1902.

[8] Ernst, A. The New Flora of the Volcanic Island of Krakatau. Translated by A. C. Seward. Camb. Univ. Press. 1908.

[9] Campbell, D. H. The New Flora of Krakatau. Am. Nat. 43: 449–460. 1909.

derived in part from the activity of nitrogen fixing soil bacteria, and in part from compounds formed in the atmosphere by electrical storms. This suggested solution of the nitrogen question is of great interest in connection with our problem.

## TAAL.

The return of vegetation to the slopes of Taal volcano in the Philippines after the destructive eruption of January, 1911, has been studied first by Gates[10] and later by Brown, Merrill and Yates[11]. Although it entailed the destruction of many hundreds of human beings, this eruption was, by comparison with that with which we are dealing, a minor affair. The depth of the ejecta on the slopes of the volcano is stated by Worcester[12] to have been only 8-12 inches, while at the foot of Katmai, eight miles from the crater, the ashfall was eleven feet on the level. It is clear, therefore, that the return of vegetation to Taal is more nearly comparable to the recovery at Kodiak than to the revegetation of the mainland areas in the vicinity of the volcano.

Gates reported that "more than 99% of the new vegetation are seedlings," but the sterilization even of the volcano island was by no means complete, "for in April, 1914, bananas were fairly abundant and indicated quite well the positions of many of the former houses" while several species of bamboo, which are likewise exclusively culture plants unable to spread without human assistance, were prominent. Since only three clumps of bananas and none of the bamboo were present in October, 1913, the indications are that these tropical plants have a capacity for undergoing long dormant periods beneath the ground, analogous to that found in the Katmai district (see page 32).

The investigations of Brown, Merrill and Yates suggest that a larger proportion of the native plants likewise, may have survived than was supposed by Gates. The most important species in the new vegetation is a grass *Saccharum spontaneum*, which "has characteristic deep seated rhizomes." From observations of the rate of growth, they believe "that the dense

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[10] Gates, Frank C. The Pioneer Vegetation of Taal Volcano. Philip. Jour. Sci. 9: Sec. C. 391–434. Pl. 3–10. 1914.

[11] Brown, W. H.; Merrill, Elmer D.; and Yates, Harry S. The Revegetation of Volcano Island. Philip. Jour. Sci. 12: Sec. C. 177–248. Pl. 4–16. 1917.

[12] Worcester, Dean C. Taal Volcano and Its Recent Destructive Eruption. Nat. Georgaphic Mag. 23: 313–367. 1912. Citation on p. 350.

stands of grass that Gates found in 1913 and 1914 would have required more than three years to develop from seed." Of the trees also, the two most abundant species, *Acacia farnesiana* and *Ficus indica*, were probably both hold-overs. *Acacia farnesiana* has a notable ability "to regenerate after the aerial portions of the plant have been killed by fire," and specimens of *Ficus indica* were "observed that had apparently sprouted from old stumps."

The return of plant life at Taal followed very much the same course as at Kodiak. There was the same initial period, when it appeared that nearly all of the old plants had perished. Writers, describing the eruption, state that its effect on plants as well as animals is "better described as annihilation than as destruction" for "not a blade of grass escaped." But then there came a sudden revival from the old roots when it seemed that complete recovery would be a matter of only a few years, and then a second pause, as the process slowed up, while the plants slowly spread against the adverse conditions.

The ejecta from Taal differ markedly from the ash of Katmai in that, instead of being composed almost entirely of insoluble materials, they contain "nearly 5% of material readily soluble in water, including 0.3% sulphuric anhydride ($SO_3$) and 0.74% chlorine. This would indicate that such ash would not form soil favorable for plants until after the water-soluble material had been leached out to a very considerable extent." This introduces a retarding factor into the problem of revegetation quite different from anything encountered at Kodiak, for the ash of Katmai has very little water-soluble material.*

## THE SOUFRIERE OF ST. VINCENT.

St. Vincent likewise has made a notable recovery since the eruption of 1902, as recorded by Sands[13], whose report has great interest in connection with the problem before us.

The depth of the covering of ejecta varied from 50 to 80 feet thick in some of the valleys, down to a few inches on steep slopes. On fairly level land, it was 1 to 5 feet. "Already quite a dense growth of shrubs, climbers, grasses and other

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* Data on the salt content of the ash are given in a forthcoming paper by J. W. Shipley, Chemist of the expeditions.

[13] Sands, W. N. An Account of the Return of Vegetation and the Revival of Agriculture in the Area Devastated by the Soufriere of St. Vincent in 1902–3. West Indian Bull. 12: 22–33. 1912.

plants has been formed. It is very evident that the greater part of this vegetation has become established from roots and seeds whose vitality was not destroyed by the eruptions. There are no trees; only a few charred trunks remain." They will, however, soon appear for seedlings are already starting. The commonest plants in the new vegetation "are the Roseau grass, Heliconia, Bamboo grass, *Impomœa umbellata* and *I. cathartica*, silver fern, Verbena, *Vitis sicyoides*, and hurricane grass; also several melastomaceous and rubiaceous bushes." Around the sites of former negro gardens are found sugar-cane, banana, and plantain. This type of vegetation continues with little change to an altitude of about 1,000 feet. "At 1,400 feet, plants are scantily distributed and the growth is poor." At 2,000 feet, silver ferns and mosses only are seen. 'From this altitude to the lower lip of the crater, approximately 2,800 feet, only algæ, mosses, and lichens are able to exist at present.' 'Around the edge of the crater, and inside for a short distance down, only two mosses, (*Pogonatum tenue* and *Philonatus tenella*), a lichen which grows in distinct circular patches (Stereocaulon sp.), and algæ, are found.' "

On the leeward side cultivation in the devastated area has been attempted only at one estate. Here, by a system of deep tillage and by utilizing large quantities of the pigeon pea and native weeds as green dressings, fair crops have been produced. These lands were covered with about 12 inches of ash, but this had been partly converted into soil by the large growth of native plants of the previous three or four years. "It still requires, however, very heavy applications of manure and organic matter to make it capable of producing average crops." But on the windward side a considerable portion of the broad plain is under cultivation in sugar-cane, cotton, arrowroot, pigeon peas and other crops. In this section scarcely anything remains to indicate that the whole district was a waste of ashes and cinders less than ten years ago.

In order to test the effect of the ash on plants, experimental plots of sugar-cane, arrowroot, sweet potatoes and ground nuts were started in the ash alone and in mixtures of ash and soil. These showed plainly "that the ash in itself could not support plant life—not a single crop could be successfully grown in it—but no sooner was a certain proportion of old soil mixed with it, or the plants were placed in the old soil, than crops, in some

cases above the average of those produced before the eruptions, were obtained without the addition of manure; but only for one, and sometimes two years. That this temporary increase in fertility was not entirely due to deep cultivation is evident by the fact that only the upper 3 or 4 inches of the old soil were touched in the process, and that it is now necessary to manure heavily to obtain average crops." The cause of this temporary increase in fertility is believed to be due, not to "any available food materials in the ash or to any improvement in the physical condition of the soil," but to the effect of the partial sterilization of the soil by the heat of the ejecta, which increases the quantity of available nitrogen compounds because of the increase of bacteria consequent upon the destruction, by the heat, of the larger organisms that prey upon them, as has been found to be the case by Russel and Hutchinson at Rothamsted.

This explanation of the temporary increase of fertility by the ejecta is very interesting as, perhaps, in a measure accounting for the widespread idea that volcanic ash has value as a fertilizer. Although the ash from Katmai was not hot as it fell, there was some suggestion at Kodiak and elsewhere of a similar stimulating effect of the ash fall.

## TARAWERA.

Among the notable eruptions of the last fifty years was that of Tarawera in 1888. This has been discussed recently in an excellent paper by Aston.[14] The following quotations will serve to summarize his conclusions:

"Occasionally, where the water-supply is favorable, lichens and moss may perform their usual function of transforming the barren rock into fertile soil, but the Raoulia must be accounted the great humus maker of this mountain. As it languishes in vigor, owing to age, from it grow other plants, the chief woody ones being Coriaria and Leptospernum, and sometimes Pittosporum, but also herbaceous plants such as Trifolium and *Rumex acetosella.* Four stages may thus be predicted for the repeopling of the plant-covering of this open area (excluding the ravines, which are able to jump the first

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[14] Aston, B. C. The Vegetation of the Tarawera Mountains, New Zealand. Trans. N. Z. Inst. 48: 304–314. 1916. The same paper is published with minor changes in the text and somewhat different illustrations in the Journal of Ecology. 4: 18–26. 1917.

and possibly the second stages): first, the patch plants; secondly, the Coriaria; thirdly, the Aristotelia, with possibly Fuchsia and Melicytus; fourthly, forest.

"If the above list of the plants collected be analyzed, it will be seen that of ninety-one species observed on the isolated northwestern face, twenty-four (or 26 per cent.) may be called bird-distributed, fifty-three (or 58 per cent.) wind-distributed, and only fourteen (or 15 per cent) are difficult to account for."

## THE GREAT PUMICE AREA OF NEW ZEALAND.

Another region, whose revegetation must have been more similar to the Katmai district than any of those yet mentioned, is an extensive area in New Zealand which was covered with a heavy deposit of ash and pumice by some prehistoric eruption. Revegetation has already occurred over this country, which has largely grown up to bushland or even to forest. A study of this area should throw much light on the processes by which the raw mineral ash is converted into soil. Such a study is not yet available, but the difficulties encountered by the colonists in attempting to utilize these lands for grazing throw a very interesting side light on the problem.

Although the forage plants grown on these pumice soils are normal, so far as reported, they are so seriously deficient as stock feed that cattle and sheep which are pastured on them shortly sicken and die of a curious malady locally known as "bush sickness." I am informed that horses may live for twenty years in perfect health on pastures which are fatal to cattle or sheep in the course of a few months. Sheep are more susceptible to "bush sickness" than cattle, and young animals more so than old. There is thus much borderland country where lambs cannot be raised to maturity, in which cattle suffer but little. The researches of Aston and his associates[15] indicate that the trouble is due to a deficiency of available iron in the forage, and considerable progress has been made toward alleviating the condition by applying some iron compound such as the sulphate to the soil. The investigation which is still in progress bids fair to throw much light on the general problem of revegetation of volcanic terrains.

[15] Aston, B. C. The Chemistry of Bush Sickness. Jour. N. Z. Dept. Agriculture 5: 121–125. 1912. Also Ibid. 3: 394. 1911. 6: 616. 1913. And other articles there mentioned.

There is one point of dissimilarity between Katmai and all of the other eruptions cited, which is of great importance in the problem of revegetation. All of these volcanoes are located in tropical countries, while Katmai is on the edge of the subarctic zone. This of itself must compel the process of revegetation to take a widely different course. The differences introduced by the climatic factor promise, indeed, to become more and more interesting as time goes on, and it becomes possible to make better comparisons of the course of revegetation here and in warmer districts.

### THE GREAT PREHISTORIC ERUPTION OF ALASKA.

Of all eruptions, the one which presents conditions most similar to that of Katmai is probably the Great Prehistoric Eruption which covered a vast area in the interior of Alaska and the Yukon territory with a thick blanket of ash and pumice. Capps[16] maps an area of one hundred and forty thousand square miles known to have received a deposit of an inch or more of ash. But his figure, large as it is, is not to be taken as an estimate of the area covered, for it is admittedly based on the incomplete data available from a country only partially explored. Near the crater, deposits of this material three hundred feet thick have been reported. This eruption though geologically recent, occurred long before historic records began in North America. Capps[17] estimates that it is fourteen hundred years old. It is evident, therefore, that the forces of erosion have had full sway. Judging from our experience at Kodiak, vast quantities of this material must have been carried out to sea by erosion. Its original mass may have been much greater than present estimates would indicate.

It is to this region that one must look for aid in predicting the course of events in the Katmai district. Here the succession of events, in the course of revegetation, must have been somewhat similar to that in our area. Unfortunately, however, this region has not yet been studied botanically, and little is known about its revegetation. In many places the ash deposit is covered with a layer of peat, which reaches a thickness of seven feet as reported by Capps[17]. But in other places, the

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[16] Capps, S. R. An Ancient Volcanic Eruption in the Upper Yukon Basin. U. S. G. S. Prof. Pap. 95 D. 1915.

[17] Capps, S. R. An Estimate of the Age of the Last Great Glaciation in Alaska. Jour. Wash. Acad. Sci. 5: 108–115. 1915.

ash remains bare with only the beginnings of revegetation. It should be possible by studying the transitions from one condition to the other, and by examining the peat, to gain considerable information concerning the sequence of events. It is very much to be hoped that results of such a study may soon be available.

### ASH POOR IN NUTRIENT SALTS.

Before taking up the discussion of the details of the recovery of vegetation at Kodiak, it will be advisable to consider the chemical character of the ash. I find that there is a widespread idea that this remarkable recovery is due to some "fertilizing" property in volcanic ash which stimulates plant growth. This idea owes its origin to the well known fertility of soils derived from the weathering of volcanic rocks, especially from basaltic lava flows. In the United States particularly, the fertility of the soils derived from the great Columbian lava flows of Oregon and Washington have been so much advertised as to have influenced the thinking of many people. Even so competent an authority as Russel says, concerning a fall of volcanic ash in the west: "This last light shower of dust * * * * added many thousands of tons of fertilizing material to the region on which it was spread."[18] A little reflection will convince anyone, however, that there is a vast difference between a fresh deposit of raw ash and a soil derived from the slow weathering of lava through perhaps a million years. There was, moreover, a great difference in the initial chemical composition of basic lava like the basalt of the Columbian region and the acid ash deposited at Kodiak. Whereas the one contains considerable quantities of the salts required for plant growth, the other, as shown by the subjoined analysis, is very low in such compounds,* having in fact practically

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[18] Russel, I. C. Volcanoes of North America, p. 287.

* Analysis made by Elton Fulmer, State Chemist of Washington for the United States Department of Agriculture. Sample was collected at Kodiak and consisted of all three layers mixed so as to give a fair average of the conditions encountered by plant roots.

| | | | |
|---|---|---|---|
| Loss on ignition | 0.65% | Lime (CaO) | 3.80% |
| Silica ($SiO_2$) | 72.16% | Magnesia (MgO) | 0.47% |
| Ferric oxide ($Fe_2O_3$) | 2.85% | Soda ($Na_2O$) | 3.86% |
| Manganese oxide (MnO) | 0.41% | Potash ($K_2O$) | 2.43% |
| Titanium oxide | trace | Sulphuric acid ($SO_3$) | 0.20% |
| Alumina ($Al_2O_3$) | 13.85% | Phosphoric acid ($P_2O_5$) | 0 36% |

Remarks: The ash is highly magnetic; in all probability some of the iron present is magnetic.

the composition of pulverized granite. If one will compare the soils derived from the weathering of granite with those formed from basalt, he will see how inapt is the comparison of volcanic ash with such soils, for granite forms a notoriously poor soil.

More direct evidence than the reasoning from the analysis, however, may be had from the results of attempts in laboratory and field to grow plants in the ash, which will be reported in a special paper. In the present connection it is sufficient to say that when such a plant as wheat is grown in the ash, it starts well and grows so long as the supply of nutriment stored in the seed holds out, but when this is exhausted the plant soon starves to death. While it is perfectly true, therefore, as has been stated elsewhere, that the ash has improved the pastures at Kodiak, this is not attributed to any chemical effect, but is to be accounted for largely by its action as a mulch, which, by smothering the smaller herbs, provided improved conditions for the stronger plants which pushed up through it; and second, by the improvement in the physical condition of the soil when mixed with the ash, for the old soil was inclined to be heavy, mucky, and poorly drained.

### CLIMATE OF KODIAK REMARKABLY MILD.

It will also be advisable before taking up the botanical features of the recovery, to discuss the climate of the district, for this has an important bearing on the course of revegetation, and like the chemical composition of the ash is subject to much misconception by those who have not given it especial attention. The Government Experiment Station at Kodiak has for a number of years kept records of temperature and precipitation which are summarized herewith (Tables I and II). These records were supplemented during the field season of 1916 by observations of some features of more especial importance to the growth of plants. The instruments used were a Friez Hygrothermograph, a battery of non-absorbing porous cup atmometers placed in various habitats, a rain gauge, and a barograph to assist in forecasting the weather, a very important item in work involving so much use of boats in the open. The continuity of the records was made possible by the assistance of my wife, who, as the silent partner in all the investigations, has contributed greatly to whatever merit the work may possess.

Kodiak has an extreme case of an "insular climate" conditioned not only by proximity to the sea, but also by the Japan current, which has the same effect here as has the Gulf Stream on Ireland. This produces a remarkably equable and very moist climate, in which, despite the high latitude (58°), the seasons are subject to considerable variation from year to year, as may be seen from the summarized data.

TABLE I.
Summary Monthly Mean Temperatures, Kodiak.

| | Jan. | Feb. | Mar. | April | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Highest of Record | 35.9 (1912) | 39.1 (1905) | 40.4 (1905) | 38.6 (1905) | 45.6 (1906) | 54.3 (1905) | 59.4 (1899) | 58.2 (1899) | 51.7 (1906) | 44.5 (1906) | 38.4 (1899) | 36.1 (1914) |
| Lowest | 22.6 (1906) | 26.0 (1907) | 29.8 (1911) | 30.8 (1911) | 40.1 (1911) | 45.7 (1911) | 48.8 (1908) | 52.0 (1908) | 45.7 (1908) | 37.8 (1908) | 31.9 (1900) | 28.0 (1911) |

TABLE II.
Summary Monthly Precipitation, Kodiak.

| | Jan. | Feb. | Mar. | April | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Highest of Record | 12.92 (1912) | 8.16 (1912) | 7.46 (1900) | 6.67 (1912) | 14.59 (1912) | 11.21 (1914) | 6.64 (1908) | 9.20 (1906) | 10.00 (1901) | 13.52 (1914) | 9.32 (1911) | 11.10 (1901) |
| Lowest | 1.00 (1907) | 0.30 (1901) | 0.00 (1907) | 2.10 (1914) | 3.01 (1911) | 1.63 (1908) | 0.82 (1899) | 2.37 (1899) | 1.50 (1906) | 1.85 (1900) | 2.28 (1900) | 1.88 (1905) |

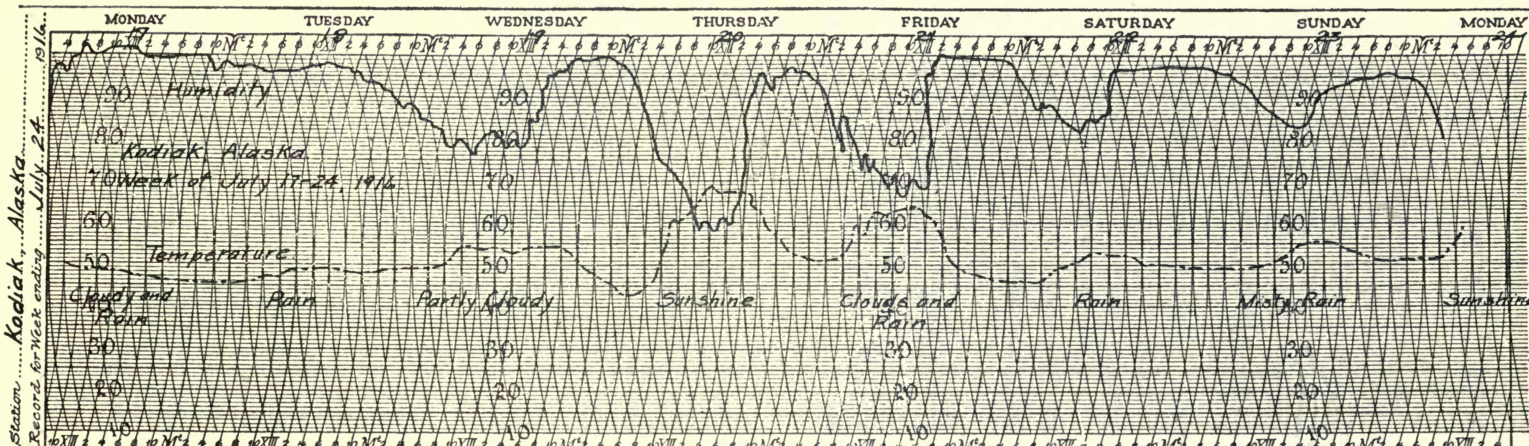
The extreme minimum temperature recorded is −12° F. But many winters pass in which the temperature does not reach zero. The extreme maximum is 82°. There is great variation in the time of the first and last frosts and the record is not long enough to give data for reliable generalizations. But the last killing frost usually occurs in May, and the first killing frost in October. The growing season is, therefore, in the neighborhood of one hundred and fifty days, which will compare favorably in length with that of the northern states of the Union.

The total precipitation averages approximately sixty inches per annum. Although heavy rains (1.50 inches) are known, the rainfall comes largely in the form of fine mist which, while holding the air at the point of saturation for days together, accumulates very slowly. For this reason, tables of precipitation and temperature are apt to give a very incorrect idea of the climate.

There are about one hundred and sixty days with precipitation of one one-hundredth of an inch or more and many more days with low-hanging clouds. The persistent cloudiness greatly cuts down the amount of radiant energy reaching the ground. But the long hours of daylight throughout the growing season, with practically continuous illumination for a month in mid-summer, must largely compensate for the weakness of the light. Measurements of the radiant energy received in this area, if compared with similar measurements in an alpine area of lower latitude such as Pike's Peak, would form an exceedingly interesting and instructive exhibit, for as is well known, the plant societies of the two regions have many resemblances. It was hoped at the beginning of the work that such records could be obtained, but conditions incident to the war made it impossible to procure the necessary instruments.

## EVAPORATION VERY LOW.

Probably the most significant records available for estimating the conditions under which the plants grow, are those of the hygrothermograph and of the atmometers. The record of the hygrothermograph for a typical week, July 17-24, 1916, is reproduced herewith. In addition, the records of the ten weeks, including the best of the growing season, during which the instrument was operated at Kodiak, may be summarized. During this period temperatures above 70° F. were reached only five times, for an hour or two only in each case. The highest temperature was 73.5°. The lowest was 40°, but temperatures below 45° were reached twenty-six times and sometimes were held for a number of hours. The lowest relative humidity recorded was 47%, and only on fifteen days was the humidity reduced to less than 60%. More significant is the fact that during twelve hundred and sixty hours or 75% of the period, the humidity stood above 80%. Inasmuch as this record was taken in the open in an instrument shelter of




THE HYGEOTHERMOGRAPH RECORD FOR A TYPICAL WEEK.
Humidy in percent, temperature in degrees Farenheit.

standard type, where humidity was at a minimum and evaporation high (see below), it is evident that there was small danger of seedlings suffering from drought in the field.

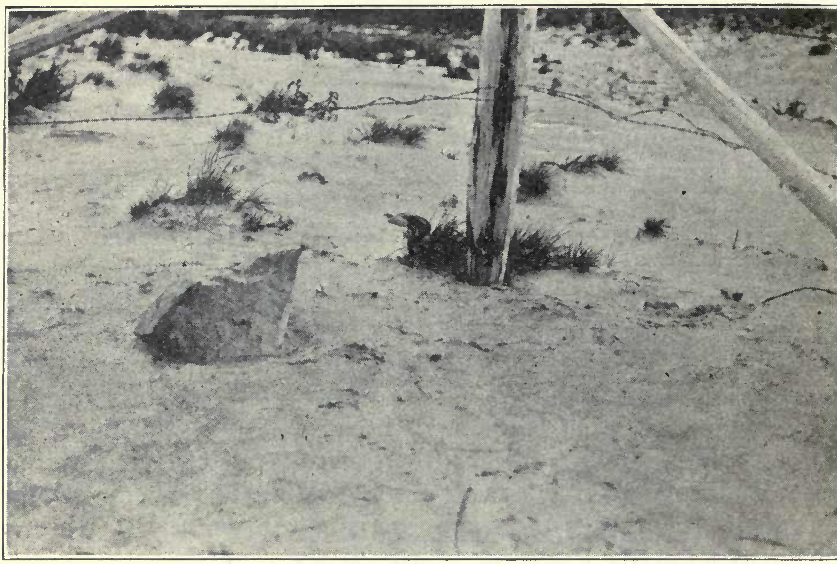
The evaporation data were taken by non-absorbing cylindrical atmometers furnished by the Plant World Company. One was located in an open school yard beside the other instruments, a second in a dense growth of young spruce trees near Vegetation Station 11, a third in an open glade formerly occupied by a small bog (Vegetation Station 12), a fourth on a steep mountain side in the Calamagrostis-Alnus association at an altitude of two hundred and fifty feet, (Vegetation Station 28), and the fifth on the summit of Pillar Mountain, a bare wind-swept situation at an altitude of twelve hundred feet (Vegetation Station 17, see page 26). The average daily evaporation rates from these instruments, corrected by the coefficient supplied with the cups to reduce it to that of the standard instrument, is given in Table III. The table gives both the absolute rates and the ratio of evaporation in the different habitats.

TABLE III. EVAPORATION DATA AT KODIAK.

Evaporation from white cylindrical porous cup atmometers reduced to standard values.

| Station | Period | Average Daily Evaporation | Percentage |
|---|---|---|---|
| Base, Schoolyard Kodiak, alt. 20 pp. | 67 days | 6.83 | 100 |
| Grass covered mountain side, alt. 375 pp. | 66 days | 6.30 | 94 |
| Summit Pillar Mountain, alt. 1200 pp. | 66 days | 9.79 | 146 |
| Opening in forest formerly occupied by small bog. | 67 days | 2.64 | 39 |
| Dense forest, young trees. | 67 days | 2.22 | 33 |

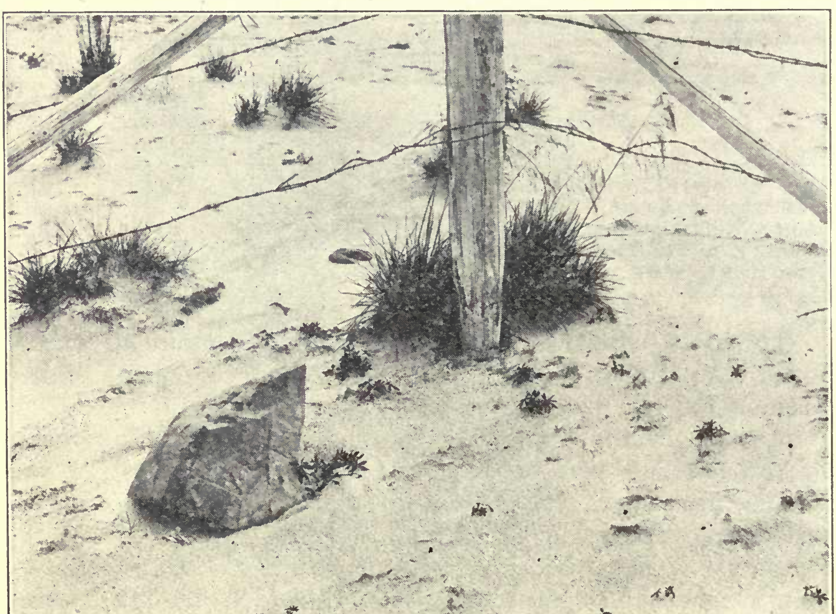
The data shown in Table III need no comment, except in the case of the mountain summit. This station was bathed in thick fog for many days when the lowland was clear. As there were usually high winds on such days, the evaporation on the lowland was often considerable, when moisture was condensing around the mountain top. Since, therefore, the period of evaporation on the summit was much shorter, the comparative rate, when evaporation occurred at all, must have been considerably greater than is indicated by the results, notwithstanding the fact that this station had a much higher rate than the base station. This is probably of great importance



*Photograph by R. F. Griggs*

VEGETATION STATION 18, AUGUST 11, 1915.

A fence corner bare of vegetation except for a few stalks of Polytrichum and the bunches of grass around the post.



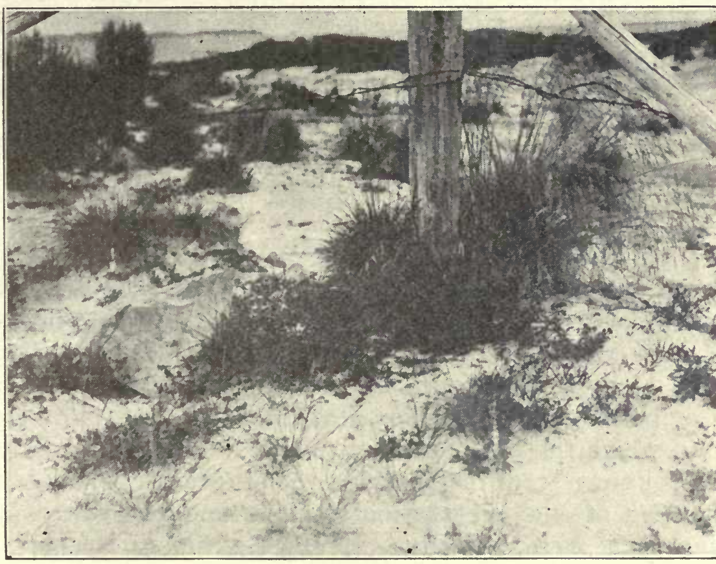
*Photograph by D. B. Church*

THE SAME STATION A YEAR LATER.

August 27, 1916. Seventeen seedlings of lupine had come up, also several grass seedlings. The clumps of grass outside the fence which prove to be *Deschampsia cæspitosa* have fruited but are not much extended.

in determining the character of the vegetation in the station, which, before the eruption, was occupied by a typical arctic-alpine heath. Instrumental records giving comparative hourly evaporation rates in such stations and the lowland would be of great interest.

More significant than the differences between the different habitats is a comparison of the evaporation rate of the region as a whole with that of other regions. Unfortunately, however, comparable data are very scanty. Briggs and Shantz



*Photograph by R. F. Griggs*

THE SAME STATION TWO YEARS LATER.

September 12, 1917. All but one of the lupines winter killed but many new ones have started. Many clumps of *Agrostis hiemalis*. Old clumps of grass much enlarged.

have shown[19] that records of the different types of instruments employed for measuring evaporation are not closely comparable. Although porous-cup atmometers of the general type used in the present investigation, have been employed for a number of years in ecological research, it is only recently that the instrument has been sufficiently perfected to correct the errors

[19] Briggs, L. J., and Shantz, H. L. Comparison of the Hourly Evaporation of Atmometers and Free Water Surfaces with the Transpiration Rate of Medicago sativa. Jour. Ag. Research 9: 277–292. Pls. 4–6. 1917.

incident to exposure under different climatic conditions. The instruments we used were of the non-absorbing or "rain-proof" type, but the new spherical cups had not yet been supplied to correct for variations in the angle of incidence of the sun's rays. The following example will, however, convey some idea of the relative evaporation at Kodiak and in the northern United States. Transeau[20], in the pioneer work of this sort, found an average daily rate of evaporation of 19.72 ccm. at his base station, the Garden of the Carnegie Institution at Cold Spring Harbor, Long Island, New York, as compared with 6.83 ccm. at Kodiak. This station at sea level near the ocean is in a general way comparable with Kodiak. But his instruments were of the old rain absorbing type, and the cup was set close to the ground, whereas ours was set about a meter above the ground. Both of these facts would tend to increase the difference between the rates at the two places.

### THE VEGETATION STATIONS.

At the inception of the work, it was recognized that the restoration of the plant cover was a process that would probably require several decades for its completion. It was deemed essential to a proper record of the progress of events that a series of permanent vegetation stations of some sort be established in which the future student might find areas whose exact history is known from the period of the eruption. The selection of the type of such vegetation stations and the best way of locating them were, therefore, among the first problems to be solved at the beginning of the investigation.

In the course of the work about one hundred definite vegetation stations have been established, partly in the vicinity of Kodiak, partly on the mainland. Some of these have already served the purpose of their establishment and observation of them has been discontinued. At others the anticipated beginnings of vegetation will not start for some years. Repeated observations through three consecutive years have now been made at more than half of these stations. In some cases the photographic records include five years, dating back to 1913 or even to 1912.

[20] Transeau, E. N. The Relation of Plant Societies to Evaporation. Bot. Gaz. 45: 217-231. 1908.

The changes that have already occurred at some of these vegetation stations have been of great service in interpreting the progress of revegetation, and the value of the record will be materially increased with the lapse of time. (See pages 22 and 23). For the present it is not considered advisable to undertake the expense incident to the publication of this rather extensive record. Later developments, however, when revegetation shall have made more progress, may very probably make it advisable to publish the record, in part at least. For the present I have contented myself with inserting, after such photographs of the stations as could be suitably used to illustrate the article, the station number, as for example on page 47 (Vegetation Station 11).

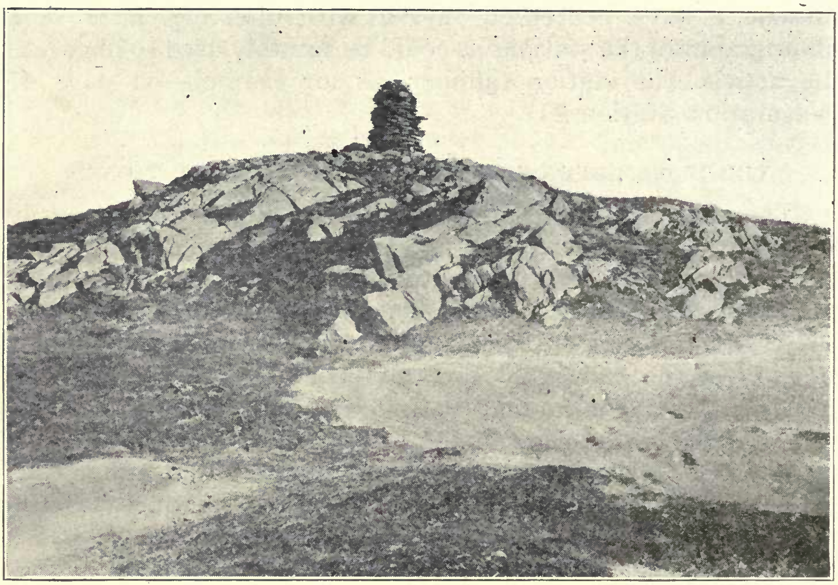
### THE DIFFICULTY OF MARKING VEGETATION STATIONS.

The selection of vegetation stations, which can be easily located in a country without the landmarks that grow up with human occupancy, was found to be a problem involving some considerable difficulty. Many of the most interesting situations observed were located in the depths of the forest far from a trail, or in the middle of a mountainside in a spot which one could hardly hope to find again himself, much less describe on paper so that another might go to it.

It will be seen at once, therefore, that the limitations thus imposed, restrict the selection of vegetation stations so that those chosen cannot be claimed to present an ideal set of stations covering all sorts of habitats within the area. Since the population is primarily maritime, the country around Kodiak, despite the fact that it has been occupied since before the time of the American Revolution, is almost untouched by the hand of man, and landmarks are very few. I have made much use of such landmarks as are available, however, for the large majority of the stations have been related to some monument of human occupancy. Aside from such places, the number of situations which can be relocated with ease is rather limited. Several of the stations have been placed on a narrow neck connecting a peninsula with the mainland. Mountain and hill tops may be located with ease and were much used. Such places are, however, to a large extent just the places most unfavorable for returning vegetation. Any station which can be seen for a distance is necessarily in an exposed situation, and wind-sweep is such a

factor in retarding revegetation, that such places will be the last to be occupied by plants, whereas one would wish to place stations in the places that will be first taken up by new plants, if he could describe locations therein.

The problem of marking the stations so that they may be found again is also one of considerable difficulty. If one intended to follow the progress of returning vegetation only for a year or two, the customary wooden stakes would serve very

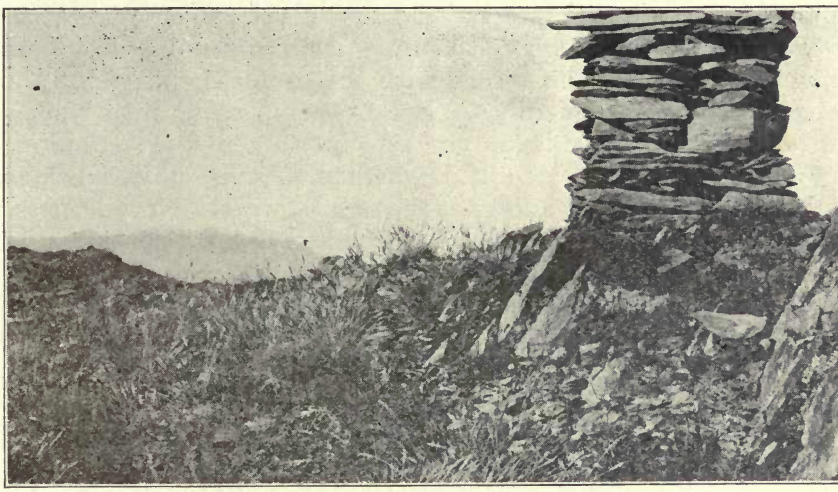


*Photograph by D. B. Church*

THE SUMMIT OF PILLAR MOUNTAIN.
Vegetation Station 17.

well. But where one wishes to follow the succession of vegetation, as in the present case, the stations should be so marked that they can be visited a hundred years hence, and this is a much more difficult matter. It was planned in advance to mark the stations with iron pins, but when it was observed that the natives have a habit of gathering up any pieces of old iron that might prove useful, such marks were seen to be even less permanent than wooden stakes. In no case where the stations are located beside a fence, abandoned house, or other human improvement, will the marker last for any such period. It has

been necessary to trust that the land-line, represented by the fence, would be maintained and the fence renewed. Where the line so chosen is the line of a government reservation, it is reasonable to expect that the line will be maintained, but in other cases it is more doubtful. In many cases stones were set on the ground to mark the position of the stations. These are subject to few natural disturbances, except movement by masses of snow, which were not to be expected in the stations



*Photograph by R. F. Griggs*

DETAIL FROM SAME STATION AT END OF FOURTH SEASON.

*Trisetum spicatum* and *Agrostis hiemalis* cover the ground. *Festuca* (ovina) *brachyphylla*, the vernal fascies, and the other alpine plants mentioned in the text, (p. 30) are not conspicuous in the photograph.

chosen. If not removed by hunters, they should remain in place for many years. But around Kodiak some of them had been picked up by the curious within a few weeks from the time they were set.

On the mainland, it seemed necessary to use the deserted houses at Katmai village for markers in the absence of almost all other landmarks. But they are falling into ruin so rapidly that there will be little left after ten or a dozen years. Fortunately, however, the stove pipes, shown in the photographs, are heavy wrought iron affairs which will stay in place for a long period. Two stones were found in the cemetery and from these, a rough system of triangulation was made, tieing together all the stations within sight of them.

Such definitive data as could be drawn from the immediate vicinity were in most cases supplemented by compass bearings on distant objects. When a station commands a view of the surrounding mountains or similar features, such bearings are the most permanent marks that can be used for its location. In other cases the bearings were taken on blazed trees, which, if uncut, will stand for several centuries, while even if cut, the stumps will persist for a long while. Theoretically compass bearings in two directions fix the location of any point, but in practice the method is open to considerable objection. It is very easy to take compass bearings from any point, but it is much more difficult to return with the compass and pick up a station from the readings. Pocket compasses, with which the bearings were taken, are not instruments of precision, moreover, and it is doubtful whether the instrument would always duplicate its readings at the same station. Nevertheless, it is believed that such compass bearings will be of considerable assistance in locating the stations after the face of the country shall have undergone considerable change.

### ADVANTAGES OF PHOTOGRAPHS OVER HAND MAPPED QUADRATS.

The most satisfactory means of locating a station, considering all things, is a photograph taken so as to show the relation of the station to distant objects. Such bearings fix the position of the camera with a considerable degree of precision. In some cases, it has been found desirable, for example, to duplicate a photograph taken soon after the eruption, which came into our possession with no data as to location except that furnished by the picture itself. Where the general location of the picture could be guessed, it was found possible to fix its exact location within a very few feet. It is believed, therefore, that the photographs are the most valuable means of locating the stations, containing as they do, much data not susceptible of description. (See pages 4 and 5).

In planning for the work before reaching the field, it was assumed that the best form of vegetation station for the work would be the meter quadrat developed by Clements. Experience showed, however, that the ground covered by a definitely located photograph makes a more satisfactory station. The photograph possesses several distinct advantages over the

method of laboriously mapping square quadrats employed by Clements. (1) It has unlimited flexibility as to size. It is as readily adaptable to the minutest group of seedlings as to a whole hillside (See page 30 and page 40). (2) In every case it records conditions with a fidelity to detail unattainable by any other method at anything like the same scale. One has only to decide with what detail a given situation should be

*Photograph by R. F. Griggs*

ALDER SEEDLINGS COME UP IN THE ASH AROUND THE FALLEN FRUITS, NATURAL SIZE.

recorded, and set up his camera at a distance suitable for rendering that detail. (3) In all but the largest scale pictures the record, by including some prominent feature in the landscape, can be made to carry its location with it more accurately than any ordinary verbal description. (See page 39). (4) It eliminates the personal equation, which becomes very large in mapping even if it is attempted to include every detail. (5) It shows many things not noticed by the observer. It often happens that the development of vegetation occurs along

unexpected lines, so that objects which at the beginning were included merely incidentally turn out to be of first importance. Station 17, for example, (see page 26) was located for the purpose of recording the return of vegetation in the foreground and no special attention was paid at the time of its establishment to the condition of the mound in the background. There was no change in the special ground designated as the station until two years had elapsed, but a striking invasion occurred the following year in the background, a detail which is reproduced on page 27.

*Photograph by R. F. Griggs*

SEEDLINGS OF RUBUS SPECTABILIS AND CHAMÆNERIUM AUGUSTIFOLIUM.

Starting in the ash beneath the shelter of the spruce trees whose needles cover the ground.

After this had taken place, it was found possible to go back to the first photograph and identify every one of the clumps of grass which sprang up so conspicuously the following year, ascertaining exactly what had happened as accurately as though a complete census of the area had been taken in the first place. (6) Beside providing much better records, photographic methods are much more rapid and, therefore, much less expensive than platting. This may not be apparent to one who does his work near home in vacations, but where considerable sums

must be spent in traveling expenses and the season for work is short, it becomes an extremely important item. (7) Photographic records may readily be reproduced at small expense, but hand made maps could be duplicated for the use of others only at considerable cost. The loss of a set of quadrat plats might upset the whole work, but a set of field prints, if lost in the vicissitudes of exploration, would be missed only temporarily.

## REVEGETATION DUE TO RECOVERY OF OLD PLANTS.

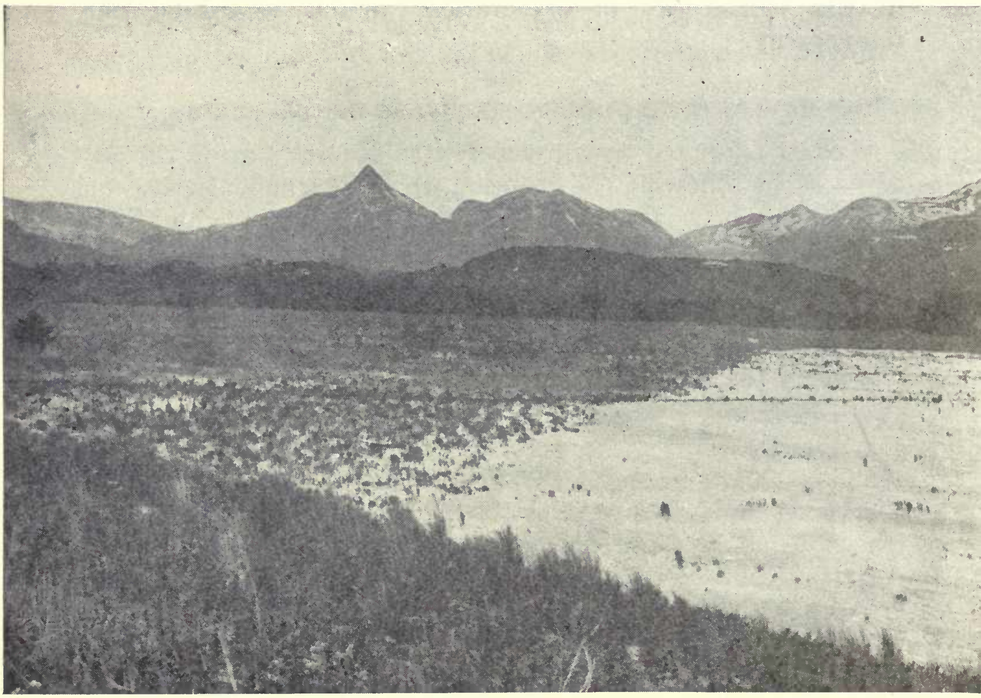
It was supposed by all who visited Kodiak during the first two seasons following the eruption, that the smaller herbaceous plants had been practically exterminated, except for a few individuals so situated that they could easily grow through the ash layer. Consequently, when the remarkable new growth of succeeding seasons was observed, it was natural to suppose that the new vegetation must consist of new plants which had started in the ash from seed.

Field study, however, at once showed the incorrectness of this view, for even the most superficial observation showed that at the beginning of the fourth season (1915), there were practically no seedlings, most of the new plants being directly traceable to the old roots. The most striking large scale demonstration of this fact is furnished by the condition of a field on the Frye-Bruhn ranch, south of Kodiak, which was plowed before the eruption. Where cultivation destroyed the weeds, no new vegetation appeared for five years, but the plants of the uncultivated land all around came up in undiminished vigor and completely covered the ground. The difference between plowed and fallow ground is so marked that it is conspicuous as far as one can see. (See pages 32 and 33).

Excavation of the underground parts of the new vegetation always revealed either a characteristic "two-storied" root system, or definitely showed the connection of the new stalks with the old soil in those plants which do not put out new roots at the surface of the ash.

### PLANTS RESURRECTED AFTER THREE YEARS BURIAL.

The belief shared by all observers, that the herbs which did not reappear during the first season after the eruption had been killed, was, of course, due to the presumption that a comparatively short period of covering would prove fatal at Kodiak



*Photograph by D. B. Church*

A PLOWED FIELD, PART OF WHICH WAS CULTIVATED JUST BEFORE THE ERUPTION.

The line between cultivated and fallow ground remains perfectly distinct after four years. Cultivation just before the eruption destroyed most of the weeds and no new ones have been able to start. The uncultivated land has grown a mass of fireweed, whose bloom is conspicuous for miles—illustrating the importance of residual vegetation.

as it would in the United States. The death of grass in a lawn, where a board is allowed to lie for a few weeks, is familiar to all. It was supposed that burial under a foot of volcanic ash would have the same effect. I was, therefore, very much astonished to find that the plants at Kodiak were able to recover from such burial. Later observations, however, showed that the recovery

at Kodiak was altogether eclipsed by that shown in some areas on the mainland, where many plants survived a much deeper burial for a longer period. For there many plants were found to have recovered after a burial of three years under an ash blanket several feet in thickness.* Definite proof of recovery after such an interval was observed in only one instance at Kodiak, but the manner of reappearance of numerous species strongly suggests that recovery after such prolonged dormant periods was as important a feature at Kodiak as at Katmai.

A number of the humbler species of plants, which could not penetrate the ash, seemed in 1913 to be practically exterminated. But some of these have reappeared in such a way as to suggest

*Photograph by D. B. Church*

THE SAME PLOWED FIELD FROM A MOUNTAIN TOP.

that the old stocks, from which the new shoots have come, lay dormant for two or three years before putting out any new growth. *Rubus pedatus*, for example, which formerly carpeted the forest floor was not seen at all in 1913. In 1915 a few plants could be found by search. But in 1916 it was common in many places, growing as vigorously as before the eruption. Of Vitis-Idaea only a single sprig was seen in 1913. In 1915 it was not uncommon, and in 1916 it was abundant. No specimens whatever of Drosera were seen around Kodiak until 1916, when a single individual was detected. *Rubus chamaemorus* likewise was not seen at all until 1916, but then was fairly common in a number of places, some of which had been repeat-

* This matter is discussed in detail in a forthcoming paper dealing with the recovery of the mainland plants.

edly collected over in previous years. Examination showed that all of these plants were hold-overs rather than seedlings. It seems hardly credible that we could have been so careless as to have overlooked them if they had put forth new growth in the previous years, for when found they were growing vigorously, flowering and fruiting freely.

*Photograph by B. B. Fulton*

FIREWEEDS INJURED BY SAND BLAST.

The few fireweeds which remain in the plowed field shown on pages 32 and 33 have had a hard time of it, being lopped over and cut to pieces or plastered up by the sand blast.

Although this situation would be difficult to account for otherwise, it may not be justifiable to assign resurrection of dormant roots as the cause for the reappearance of these species on such slight evidence. But in *Equisetum arvense* crucial proof, of the ability of the underground parts to retain their vitality when buried, was furnished when I found an old rhizome of this species which I had exposed in excavation in 1915 that had put forth new shoots the following year. This had been lying water-soaked in an old bog for three years. When dug up, all of the plant remains, of which it was a part,

were blackened by bacterial action and were unhesitatingly pronounced dead. The circumstances were such as to leave no manner of doubt that the new growth had come from part of this supposedly dead material, for the new shoots were coming

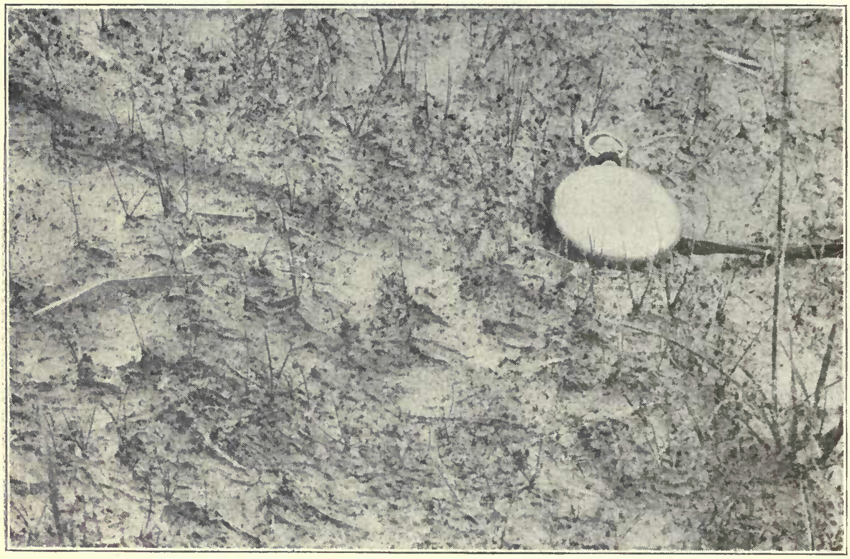
*Photograph by R. F. Griggs*

*RUBUS PEDATUS* GROWN THROUGH THE ASH.
This species did not reappear in numbers until three years after the eruption.

out of old rhizomes still embedded in the clods, as I myself had removed than the year before in establishing one of the vegetation stations. The material was, moreover, lying on a bare ash flat without other vegetation for many feet round about.

## DIFFICULTY OF STARTING SEEDLINGS IN THE ASH.

More significant, perhaps, than negative observations indicating the absence of seedlings, are the results of the attempts that have been made to seed down various ash covered areas. At the Government Experimental farm at Kalsin Bay a number of pasture grasses were planted soon after the ash fell. The seeds came up well, giving an almost perfect stand in nearly every case. Where heavily manured, many of the plots have continued to do well, and some of them have formed a good turf on the ground.



*Photograph by R. F. Griggs*

A TIMOTHY PLAT THREE YEARS OLD.

Sowed in the ash soon after the eruption, the seed came up well and most of the plants are still alive but have made no growth. Contrast with the grass come up from old roots, shown on page 7.

Where planted in the untreated ash or with little fertilizer, different species have behaved differently. In some, most of the plants were overwhelmed while yet small, but a few individuals managed to get a good start and are now strong enough to hold their own against the undermining wind, while in others most of the original plants have persisted, but have made only very slight growth. On the timothy plot, for example, most of

the plants are still living, but after four years are only three inches tall. (See page 36). The contrast offered by such plants with grasses which have come up from the old roots (see page 7) is too striking to need further discussion. The importance of surviving plants in the revegetation cannot be overestimated. Where for any reason none of the old plants persisted, the ground remained as bare as when the ash first fell, for no seedlings were able to start in such places. The reason did not lie in the sterility of the ash, for as will be seen, this can be overcome where the surface is stable enough to give the young plants a chance. The trouble is that the ash, having the consistency of fine sand, is kept moving so rapidly by the wind that seedlings have no chance except in sheltered places.

*Photograph by R. F. Griggs*

ASH DRIFT LODGED BEHIND FIREWEEDS.

The drifts bear every appearance of snow banks. The fireweed endured such burial for three years but then succumbed.

### ASH DUNES LIKE SNOW DRIFTS.

One of the most striking examples of the effect of wind action was in the plowed field above referred to. Here every passing gust of wind picked up a cloud of dust, while the heavier sand particles were swept along the ground. Volcanic ash is composed of angular fragments of glass far sharper than ordinary sand. The sand blast was thus very hard on all plants exposed to it. The few weeds which escaped the plow and came up through the ash in the open part of the field were

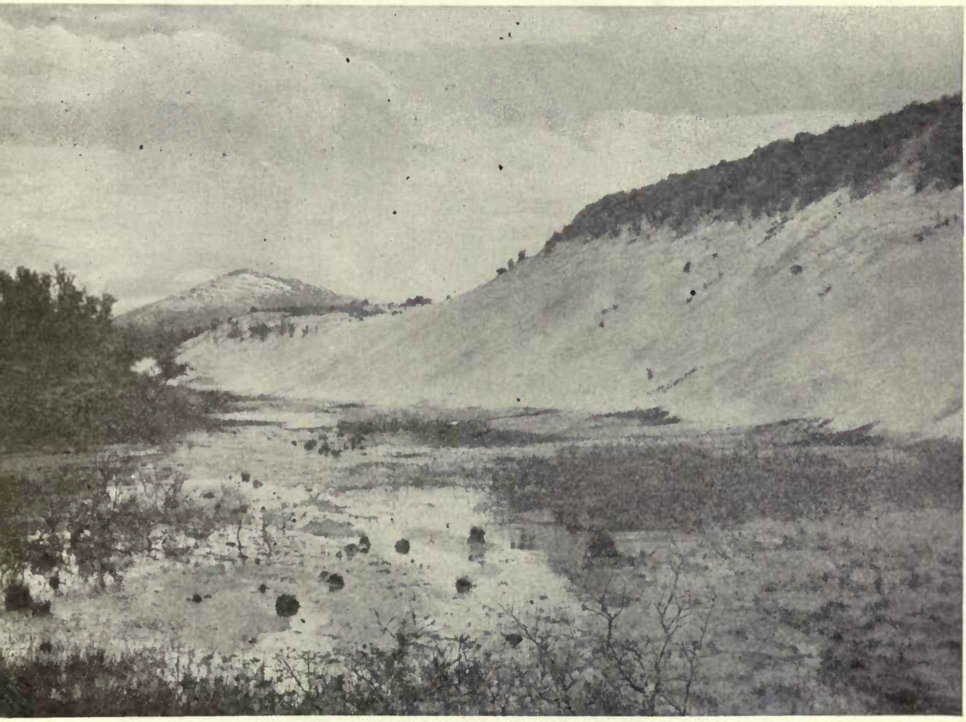
nearly destroyed by the sand blast. They were all lopped over before the wind, and their lower leaves either cut to pieces or so plastered with the drifting ash as greatly to interfere with their functions. (See page 34). Where the plants stood thicker, on the other hand, at the edge of the field, they checked the moving sand which formed conspicuous drifts behind them. (See page 37). These drifts follow exactly the familiar forms of snow drifts. Some of them are several feet deep, forming shifting dunes very like those of the sea shore. Where such dunes were caught by growing vegetation, the plants have had a severe struggle to maintain themselves. The more rapidly new growth was pushed out beyond the engulfing sand, the more drift did the plants catch and the higher must they grow

*Photograph by R. F. Griggs*

HILLOCK OF DRIFTING ASH CAUGHT BY A WILLOW WHICH IS OVERTOPPING THE OBSTRUCTION BY ITS GROWTH.

to clear it. Many plants in this way surmounted drifts much thicker than they could have penetrated if they had accumulated all at once. In some cases, as in the willows, where the plants could readily send out new roots into the sand, they are probably little the worse for their experience. (See cut above). But plants like the fireweed, which have no such capacity, were soon so deeply buried that it overtaxed the conducting system to maintain the connection between the leaves and roots. At the edge of the field in question, they held out for four seasons and at the end of 1915 were apparently unaffected by the struggle. But the next spring they failed to come up, showing that

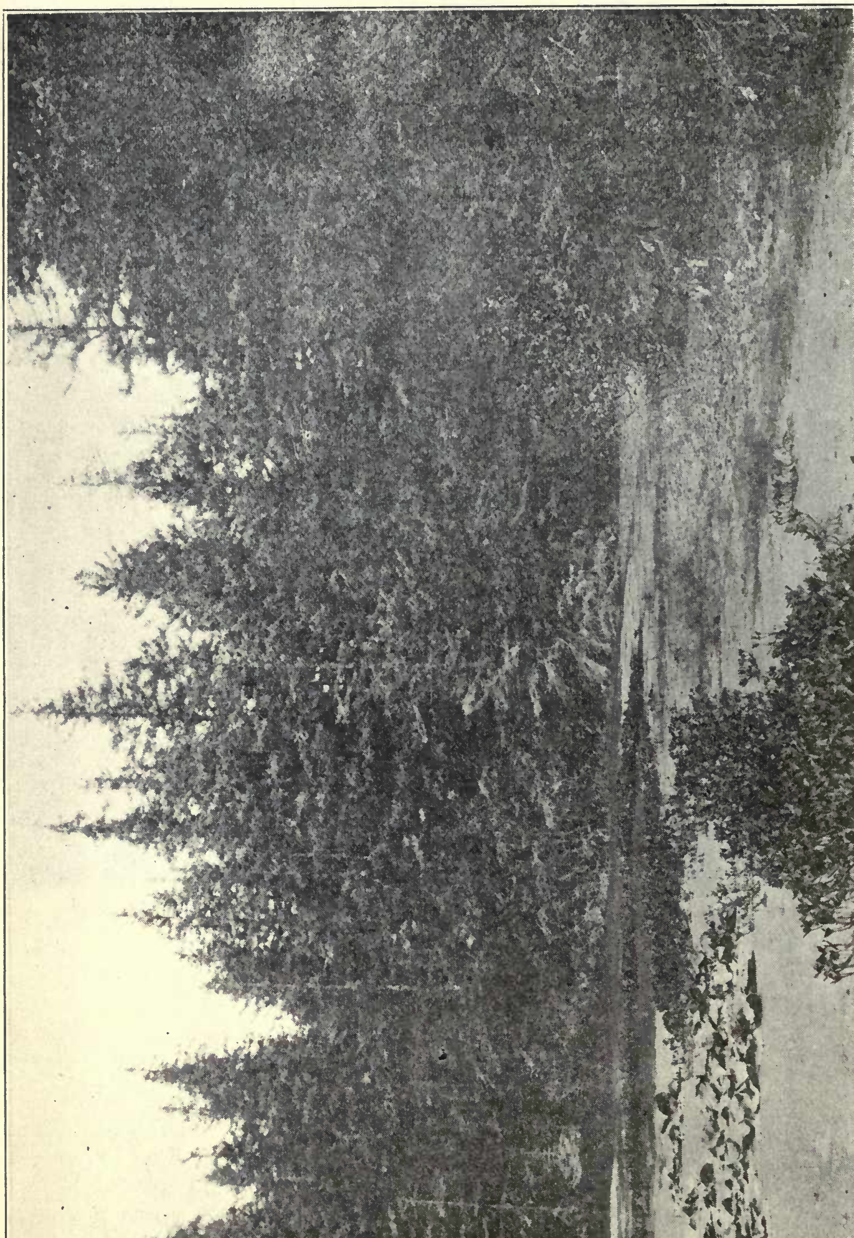
the dune had finally been too much for them. It is obvious that no new plants can gain a foothold so long as such conditions prevail. Any seedlings that start are either promptly undermined, blighted by the sand blast, or buried beneath the drifts.



A DUNE OF WIND-BLOWN ASH NEAR KODIAK.
The rapidly shifting surface makes it impossible for plants to start.
(Vegetation Station 59).

QUICKSANDS IN THE SWAMPS.

Quite a different set of conditions prevail in the numerous swamps, shallow ponds and tundras which were formerly common. Here also the deposit of ash has been increased by secondary accumulations, in this case brought down by the streams. There is no tendency for this ash to blow about for it is kept constantly soaked. It is, moreover, of quite a different physical constitution from the loose sand of the dunes. It should be explained that there was a marked difference in consistency between the three layers of ash as they fell.



*Photograph by B. B. Fulton*

AN ASH-FILLED POND.

The circle of Menyanthes (center) marks the former edge of open water in which grew the waterlilies. The outer zone was a sphagnum bog. The bog was destroyed but the aquatics have come through the ash. (Vegetation Station 13.)

The bottom (gray) layer was made up of fairly large particles, giving the deposit the character of fine sand; the second (terra cotta) layer was very much finer, almost all dust; while the top layer (gray) was similar to the first but very much finer. The top layer has almost everywhere blown away, leaving the present surface of the ash composed usually of the middle brown layer.

Because of the fineness and angularity of the particles, the physical properties of this layer are very peculiar. When dry, it is all blown away in a cloud of dust by the gentlest breeze. But when moist, the particles settle close together, interlocking one with another, till they form a hard compact terrain which coheres almost as though the particles were cemented together. If more water is added there comes a point at which the interlocking particles are floated free from each other, and the mass suddenly changed from a rigid solid to a perfect liquid. This layer, therefore, in the wet climate of Kodiak, is little affected by wind action, but is rapidly eroded by the streams, and it is this fine material especially which has accumulated in the ponds and tundras, sometimes to the depth of several feet. In such deep beds, the facility with which its condition changes from solid to liquid becomes a matter of considerable moment. This change may often be brought about suddenly by stirring the mixture, without the addition of more water. It will be seen that there are here conditions favorable to the formation of dangerous quicksands. In the examination of such places, one often finds on retracing his steps that the place, over which he came on hard ground but a moment before, has become a soupy liquid under the disturbance caused by his tread. Several men have been seriously mired in such places.

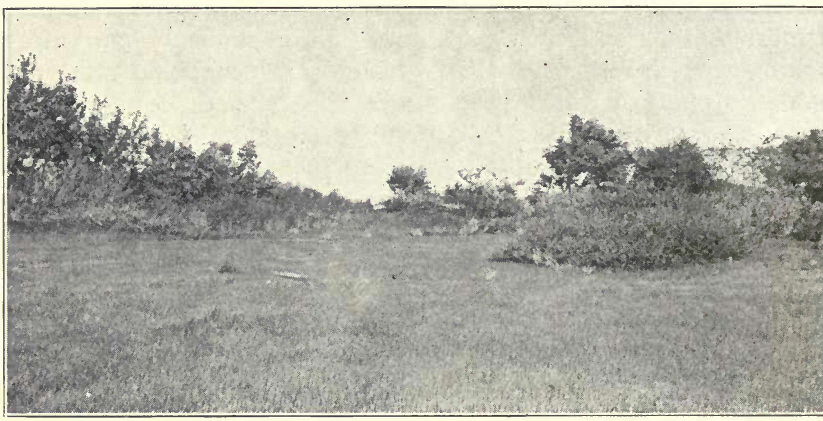
### POND PLANTS LARGELY SURVIVED.

Where the ash deposit in the filled ponds is wet enough to remain in a semi-fluid condition, the original aquatic vegetation has to a large extent recovered, and is thriving as before the eruption. A little pond in the forest north of Kodiak (see page 40) will furnish a good illustration of the situation. So much ash has been washed into the pond that it is completely filled up, so that the surface remains dry and hard during dry periods. In the center, formerly covered with open water, are water lillies (*Nymphaea polysepala*) thriving apparently as well as ever, for they flower and fruit abundantly. Surrounding the former open water is a zone of buckbean (*Menyanthes trifoliata*)

likewise in good condition. Here and there are also clumps of Mare's tail (*Hippurus vulgaris*). The first and last are apparently spreading merely by vegetative means, but there are many seedlings of Menyanthes on the bare surface round about, which give every indication of establishing themselves.

### BOGS PRACTICALLY DESTROYED.

The ring of buckbean was formerly surrounded by a Sphagnum bog or tundra. This, like all the bogs, was practically exterminated by the eruption. Sphagnum, and the plants associated with it, are of such weak growth that they were not



*Photograph by R. F. Griggs*

A CARPET OF HORSETAIL IN A FORMER BOG.

Many of the old bog areas have come up in a pure stand of Equisetum arvense which has kept the ash from blowing away and serves as a "nurse" for seedlings of other plants.

able to pierce the ashy blanket. Where only two or three inches of ash remained on the bog plants, they were apparently as hopelessly buried as when covered ten times as deeply. Only here and there, where the Sphagnum occupied a steep bank which was quickly cleared of ash, did it survive. The fate of such buried bog areas is one of the most interesting problems in connection with the revegetation of the country. Bog and tundra are so abundantly developed in all northern countries, that it is to be supposed that they are favored by climatic conditions, and hence their return may be expected in the Katmai district. There are not enough bog plants left, however, to reseed the areas so that in any event the general return of bog conditions must be long delayed.

HORSETAIL VERY IMPORTANT AS THE FIRST GROUND COVER.

At present the former bogs remain quite bare or are grown up with *Equisetum arvense.* In most cases the Equisetum appears to have been restricted to the edges of the bog before the eruption. In such bogs the middle remains bare ash, but the horsetail is sending long runners toward the unoccupied areas and will soon cover them. (See pictures below). While the old bogs are perhaps the most conspicuous examples around Kodiak of the ability of the horsetail to cover ground which would otherwise have remained bare, there are many other areas

*Photograph by R. F. Griggs*

EQUISETUM SENDING RUNNERS INTO BARE ASH.

Equisetum has occupied large areas which otherwise would have become dunes of drifting ash. Its importance in the revegetation of the country cannot be overestimated.

where it was almost the only survival, as was brought out in an earlier paper (Griggs[2], 1915). It was by far the most important species of the flora in providing a new plant cover on the ash.

Its importance in the recovery of the country can hardly be overestimated, for over large areas it was for a long time the only ground cover. This was even more conspicuous in certain parts of the mainland than at Kodiak, for here there were literally many square miles of horsetail in pure stand. Although this cover of horsetail was of little value in itself, its service in protecting the ash surface from wind was of the greatest impor-

tance. There can be no question but that its presence greatly mitigated and shortened the period of the prevalence of the dust storms which afflicted the country after the eruption. It provided, moreover, a protection that gave very great assistance to the seedlings of other plants. Many areas now support an abundance of seedlings which would undoubtedly still be barren wastes if it had not been for the Equisetum (see cut below).

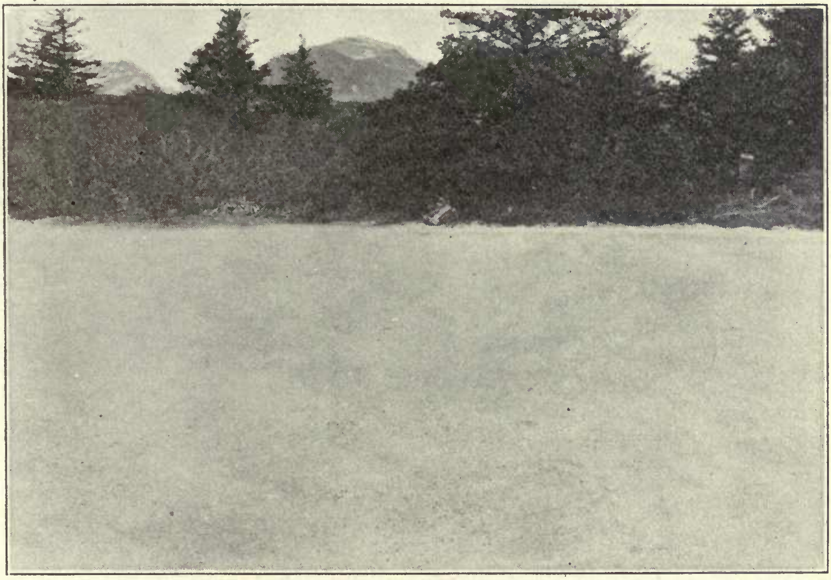
*Photograph by D. B. Church*

A TURF FORMED BY SEEDLINGS OF DESCHAMPSIA CÆSPITOSA.
These came up under the protection of a rank growth of the pioneer horsetail which has been cut away in the foreground to expose the grass.

### HARD COMPACT BEDS OF ASH.

Returning now to the areas occupied by fine grained ash, one other set of conditions rather commonly encountered must be described. Where masses of fine terra-cotta ash are so situated as to be kept well drained, the particles "set" together so as to form a compact hard mass very unfavorable to plant growth. Laboratory experiments with this material show that seedlings grown in it are at a considerable disadvantage as compared with those in the coarser grained ash. The difficulty is probably due to lack of aeration, as well as to the mechanical obstacles to root extension offered by such a compact hard "soil." The analyses show that it is not due to any deleterious chemical in the material. Buckwheat, which was planted in an area of

such ash, was red, dwarfted, and malformed, and did not advance beyond the cotyledon stage in the course of six weeks. It is not surprising, therefore, to find the areas covered by this material absolutely bare except where pierced by the old plants from beneath. (See cut below). Since the ash is composed of the most insoluble materials, there is no reason to expect a change in its physical condition. It is difficult to see, therefore, how vegetation can ever start in such areas. Some of those



*Photograph by R. F. Griggs*

A DRIFT OF CLOSE PACKED ASH UNSUITED FOR PLANT GROWTH.
Buckwheat planted here had not passed beyond the cotyledon stage in six weeks. (Vegetation Station 14.)

chosen for vegetation stations are so located that the ash accumulation is not likely to be eroded away. Their future history will be watched with interest.

### MESH-WORK OF MOSS ON THE FOREST FLOOR.

Except for the ponds, most of the habitats so far discussed belong to the open country westward from Kodiak. In the shelter of the forest to the eastward, the conditions for the growth of seedlings are much more favorable[21].

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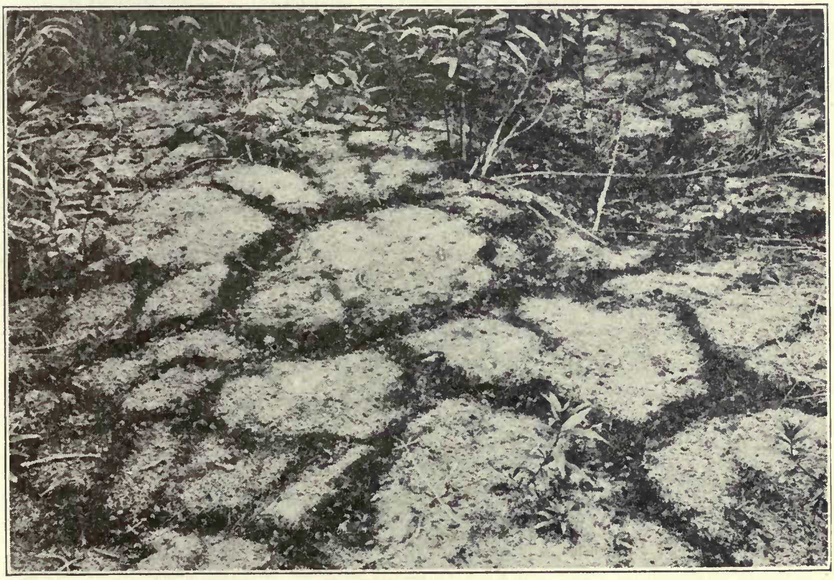
[21] Kodiak stands at the line separating the great Pacific coniferous forest from the open grassland beyond. For a discussion of the ecological aspects of this transition see: Griggs, R. F. Observations on the Edge of the Forest in the Kodiak Region of Alaska. Bull. Torr. Bot. Club. 41: 381–385. 1914.

*Photograph by B. B. Fulton*

MASSES OF MOSS ON THE TREES NEAR KODIAK.

These moss balls held quantities of the falling ash which have since been consolidated and bound in place by the growth of moss.

The trees themselves were but little affected by the ash fall, although their branches were heavily loaded, and in places still retain considerable ash. (See page 48). In the deeper parts of the forest the branches bore great masses of moss, which, of course, caught and held quantities of ash. During the interval that has followed the moss has grown out over the ash, making larger masses than ever and giving the trees a very bizarre appearance. (See page 46).



*Photograph by B. B. Fulton*

THE MESH WORK OF MOSS ON THE FOREST FLOOR.

Wind borne spores lodged in the mud cracks whose position was thus indicated by a growth of moss long after they had been filled up by drifting ash. (Vegetation Station 11).

The most striking feature of the revegetation of the forest, however, is to be found on the ground. When the ash dried out after the first heavy rains following the eruption, deep cracks appeared like the mud cracks in a dried-up puddle. (See pages 4 and 48). These cracks are, of course, long since filled up by drifting ash, but a heavy growth of moss (*Amblystegium* sp.) has come up in every crack, giving the ground a most curious reticulated appearance. (See cut above).

*Photograph by George C. Martin*

"MUD CRACKS" IN THE ASH AFTER THE ERUPTION AUGUST, 1912.

The cracks were 2 inches wide and 6–8 inches deep. For a long time the only plants to reappear came through such cracks. (Cf. page 47).

This curious distribution of moss is apparently due to the fact that the spores found lodgment in the cracks. The same moss often starts around fallen sticks or other objects which wind-borne spores would settle. One of the most striking instances of this was a sea-urchin shell, dropped by a raven, which was embedded in a mass of moss that had grown up around it.

### SEEDLINGS OF ALL SORTS STARTING IN THE FOREST.

In the forest the trees protect the ground from the wind, and insure a stable surface on which new plants can start. It was sometime after the eruption, however, before seedlings made their appearance in any numbers even in the most protected situations. None were observed in 1913 and in the beginning of the season of 1915 they were very few and far between. But during the latter part of the season of that year, they began to appear in numbers. These seedlings included representatives of all the important members of the flora including among others: *Picea sitchensis*, *Alnus sinuata* (see page 29); *Populus candicans*, *Rubus spectabilis* (see page 30); *Calamagrostis langsdorfii* (see page 50); *Deschampsia caespitosa* (see page 44); *Archangelica officinalis*, *Heracleum lanatum*, *Echinopanax horridum*, *Lupinus nootkatensis* (see page 55); *Sanguisorba sitchensis*, *Solidago lipida*, *Agrostis hiemalis* (see pages 23 and 27); *Agrostis meleleuca* and *Chamaenerium angustifolium*, (see page 30). All of these except the last were common in many places.

The presence of large numbers of such a variety of seedlings dispelled all doubts which may have previously been entertained concerning the ability of seeds of plants to germinate in the ash. Almost without exception, moreover, they weathered the drought of the first summer, which was unusually severe for that region and were in good condition when we left the field in September. But they were not yet sufficiently abundant to be of any ecological consequence and it remained to be seen whether they could survive the winter.

### SOME SEEDLINGS SURVIVED THE WINTER.

The winter of 1915-16 was extremely long and severe. The ice did not break up in the ponds until after the first of May. The minimum temperature was not very low, only +8° F., but the vegetation suffered severely. Many spruces,

especially small ones, succumbed, and the canes of *Rubus spectabilis* were so severely winter-killed as to seriously diminish the crop of berries the following year. Under conditions so exceptionally severe, a high mortality was to be expected among the seedlings which, being dependent for their nutrition exclusively on roots distributed through the sterile ash, were not as well nourished and in as good condition to resist unfavorable

*Photograph by D. B. Church*

GRASS SEEDLINGS IN THE ASH.

Coming up under the shelter of old clumps of the same species, *Calamagrostis langsdorfii*. (Vegetation Station 44.)

influences as though they had grown in normal soil. It was found on examining them the next spring that, as was expected, the mortality had been very high. Nearly all of the special seedlings that had been marked for observation had perished. But, notwithstanding the high death rate, large numbers had survived, and the renewal of growth showed that they would be better fortified against the next winter.

Seedlings were similarly starting in sheltered places beyond the forest. Beside many a strong clump of grass, for example, the ash surface was fairly covered with small seedlings, presumably of the same species. (See page 50.) In many places beneath the omnipresent Equisetum such seedlings, especially those of *Deschampsia caespitosa*, were so thick as to form a veritable turf over the ground. (See page 44). In less sheltered situations, the seedlings often appear along the lines washed by the run-off from rains. (See cut below). A similar phe-

*Photograph by D. B. Church*

SEEDLINGS COMING UP WHERE "PLANTED" BY STORM WATER.
*Polygonum aviculare* and a grass. The intervening spaces where the seeds, presumably present, were not covered by washed-in sand are bare.

nomenon was observed much more conspicuously in Katmai Valley and will be discussed in detail in a succeeding paper. It is believed to be due to the fact that the running water buries the seeds beneath a layer of ash, thus preventing their blowing away and giving them a chance to start.

Beside these yearling plants were a very few others, especially of spruce and alder, which had started in earlier years and persisted. These were continuing to grow slowly. Some of

them had almost succeeded in getting their roots through the ash layer and into the original soil beneath. When this connection is once made, the seedling is removed from the problem of revegetation of the ash, and the factors controlling its success or failure are the same as those affecting similar seedlings outside the ash-covered area.

### SALT MARSHES RESTRICTED BUT RETURNING.

Another type of habitat, whose revegetation requires separate consideration, is the area formerly covered by salt marshes.

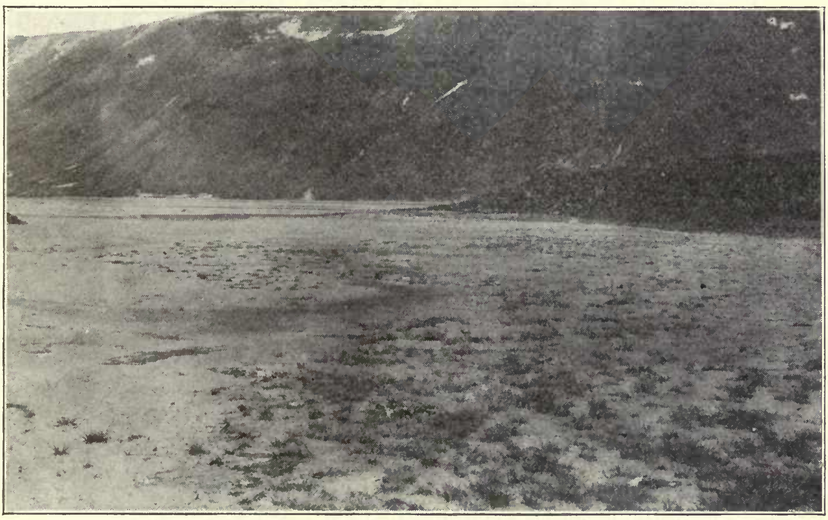
*Photograph by R. F. Griggs*

A SALT MARSH ON CHINITNA BAY.

Giving a very good idea of the general character of the salt marshes of the devastated district before the eruption.

This association throughout the southern shore of Alaska differs considerably from the more familiar salt marshes of lower latitudes in the greater simplicity of its composition. For here, instead of being a varied association including *Salicornia* and other plants conspicuously adapted structurally for a halophytic existence, the salt marsh is often composed of a pure stand of a single grass, *Puccinellia* sp. When other plants occur they are in such small numbers and so scattered that they may be considered as accidental rather than as forming definite components of the association.

The ash fall around Kodiak effectually buried the salt marsh vegetation, and the conformation of the ground is such that the ash layer does not erode away rapidly in such places, but rather has been increased by subsequent deposition. This has not only prevented the revival of the original plants, but, by raising the level of the land, has so altered conditions that considerable areas, formerly overflowed by the tide, are now above its reach. It is to be doubted, therefore, whether salt marshes will become so numerous as before the eruption.



*Photograph by D. B. Church*

A SALT MARSH STARTING ON AN ASH FLAT.

The plants are mostly Puccinellia amongst which may be seen numerous fragments of decaying algæ, principally Fucus. (Vegetation Station 47.)

It is only at a few places that one can look for the stages in their return. In one such place examined, numerous seedlings of *Puccinellia Alaskæ*, together with *Atriplex Alaskæ*, had started, and had reached reproductive maturity. (See cut above). But the plants stood apart from each other and had not made much progress toward the formation of the thick turf characteristic of the original salt marsh. (See page 52). No progress in this direction was shown between 1915 and 1916. But this may have been due to the severity of the intervening winter.

The ash on which the salt marsh plants were starting was foul with decaying algæ on the surface, and beneath it was blackened by bacterial action and emitted a strong odor of hydrogen sulphide. This was taken to indicate that subsoil conditions did not differ greatly from the normal salt marsh. The complete re-establishment of the salt marsh is, therefore, expected before many years have passed.

### PROBLEMS OF THE FUTURE.

It is already clear that the recovery at Kodiak is permanent. For, with the demonstration that seedlings can start in the ash, it is evident that any gaps which may develop in the ranks of the old vegetation will be promptly filled by new plants starting from seed.

The problems of the future in this area concern, first, the fate of the exposed habitats where the surface is at present too unstable to admit of revegetation, and second, the succession of plants which will develop as the first ephemeral plant cover shall give way to more permanent vegetation, for it appears quite likely that the stages in the course of succession toward the climax associations of the country will be materially altered by the disturbance caused by the eruption.

### ASH BEING RAPIDLY REMOVED.

The unstable conditions caused by the shifting sand will be, for the most part, of short duration. Where the ash layer was only a foot thick originally, it does not require a very long period for the wind to remove the whole deposit. Indeed, in many exposed places, the ash is already completely gone. And in any case it will be only a few years until the large part of the ash from the mountains has been blown out to sea. Even on the level, some places, where the wind has a clear sweep, have been nearly cleared already. Thus the field at the Frye-Bruhn ranch, repeatedly spoken of above, retains at present only enough ash to veil the black soil beneath, and the sand blast is almost a thing of the past. The conditions no longer offer any obstacle to revegetation, and in 1916 lupine seedlings came up thickly over the whole area. (See page 55). These were able to penetrate the ash and reach the old soil immediately with their roots, so that in another year the whole bare field will be green with lupine.

In places sheltered from the wind, erosion by water has proceeded so rapidly that where the land is at all steep (and Kodiak is a very rugged country), nearly all of the ash has been washed away. On the average grass-covered mountain sides, the present covering of ash amounts to only an inch or two and this is so mixed with plant stems and roots as to form a very indefinite layer. Erosion has proceeded so rapidly that even now it appears almost incredible to a stranger that the ash stood a foot deep only four years ago. I should hesitate to believe

*Photograph by R. F. Griggs*

LUPINE SEEDLINGS.

These have come up thickly in the plowed field shown on pages 32 and 33. They did not start until practically all the ash had blown off, just enough now remains to conceal the soil beneath.

it myself if I had not seen it with my own eyes. Within a century, volcanic ash will become almost as much of a curiosity at Kodiak as it is at other places. Long before any such period has elapsed it will be difficult to secure enough for a good specimen, except from a few special places.

Another factor, which is tending to destroy the identity of the ash as a separate layer, is the action of earthworms. The importance of these animals in ordinary soils is too well known

to require mention. One frequently sees their castings at Kodiak voided on the ash surface. From the character of the castings it would appear that the worms are confining their activity to a large extent to the ash itself, but even so, their action will serve to bury increasing quantities of vegetable debris. And where they bring up the old soil from beneath, they will thoroughly mix ash and soil till the ash layer becomes hardly recognizable.

Of succession it is too early to speak or even to make predictions. Within five years, however, some indications may be expected which will give a clue to the future course of events.

### ALPINE HEATH ON THE MOUNTAINS BEGINNING TO REAPPEAR.

Not directly connected with the problem in hand, but yet one of the results of the eruption, is the opportunity afforded by the devastation of the mountain tops to study the stages in the re-establishment of the alpine heath. The prostrate alpine plants occupying the summits had no capacity of sending up shoots through the ash layer, but were effectually buried beneath it. Long after the lower slopes were green with tall grass, which had come through the ash, the mountain tops remained gray wastes.

But such exposed situations were naturally the first to be cleared of ash by erosion, leaving large areas of the original surface with the soil in exactly the same condition as before the eruption. Doubtless a large proportion of the old roots remained alive as in lower altitudes, but the sand blast about the summits was so much more severe than at lower levels, that over considerable areas all of the antecedent vegetation was destroyed. These areas, therefore, give an unparalleled opportunity to study the process of the establishment of the Alpine heath, which association at Kodiak is very similar to that occupying the tops of high mountains generally.

The first stages in the revegetation of these summits have already appeared. On some of the mountains, new grasses have sprung up, apparently from seed, which almost cover the ground to the exclusion of other plants, forming in places a real turf. The most important of these are *Festuca* (*ovina*) *brachyphylla*, the vernal fascies, and *Agrostis hiemalis* var., the autumnal fascies. (See page 27). In other places, the dwarf Alpine

harebell, *Campanula lasiocorpa*, has come in. Considerable areas were found in 1915 where small seedlings of this species were almost the only plants except for occasional hold-overs. The year following they had matured and were flowering in great profusion. The only other plant which at present gives promise of becoming an effective pioneer is the lupine, which, in 1916 for the first time, appeared in numbers on the mountains as well as on the lowland. There were, to be sure, other areas where a more varied flora has made its appearance, but as there was reason to suspect that these plants are survivals rather than seedlings, they will not be considered here.

It is confidently expected that, as the development of the mountain heath shall proceed, it will provide a most interesting and instructive insight into the conditions of life of the arctic-alpine flora which is a matter greatly to be desired.

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If, in conclusion, we may attempt to generalize for the benefit of other countries, which might be similarly afflicted, we must recognize that the experience of Kodiak is decidedly reassuring. The damage to vegetation by an eruption is not likely to be as great as at first appears. Where the ash fall is a foot or less, no permanent injury to agricultural interests is to be expected. It would be very foolish for the people in such a region to abandon their property and go elsewhere, as some were inclined to do at Kodiak.

Scientific Results of the Katmai Expeditions of the National Geographic Society.

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## II. ARE THE TEN THOUSAND SMOKES REAL VOLCANOES?*

Robert F. Griggs.

In the original account of the discovery and exploration of the Valley of Ten Thousand Smokes in the National Geographic Magazine, February, 1918, I felt free to describe the phenomena in the light of our conclusions regarding them, although I could not, at that time, digress to give the data upon which our conclusions were based. This paper is written with the purpose of supplying the data that could not be elaborated in the former account, in order that the student of volcanic phenomena may judge for himself the validity of the conclusions reached.

It should be emphasized at the outset that, while there are certain conclusions concerning the nature of the Valley of Ten Thousand Smokes which may be considered to be well supported by indubitable evidence, there are also many larger problems looming in the background which as yet can hardly be stated with clearness, much less solved.

The primary question which must arise in the mind of anyone who considers the Valley is as to the nature of its activity. Are its smokes real volcanoes? Or are they of a more superficial character caused merely by the vaporization of surface water? It is evident enough that such a Valley full of "Smokes" might be due, either (1) to the percolation of surface waters down through the fragmental ejecta of the recent eruption to a flow of lava beneath, which, though erupted before the fall of ash, still retains a high temperature and vaporizes the water that comes in contact with it; or (2) the smokes might derive their gases from molten magma beneath the surface, in which case the vents would be as truly volcanoes as is Vesuvius itself.

Certain of the features of the Valley seem to favor each of these hypotheses. It will be well, therefore, to pass these facts in review. But before doing so, it will be desirable to

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THE COOK STOVE OF THE EXPEDITION. *Photograph by D. B. Church*

This was one of the cooler vents, (100° C.). Comparison with page 107 will show how insignificant this is in comparison with the big vents shown in the distance. The notch in the contour of the hill at the right is the fault shown in detail on page 115, here two miles from the camera.

comment on the two hypotheses themselves. Everyone would prefer to explain the Valley as a superficial phenomenon, if such an explanation is possible, for that would bring into play nothing unusual in volcanic phenomena and would involve no far reaching theories. If, on the other hand, it is held that the smokes are truly volcanic, then it will have to be admitted that the formation of the Valley was an event without parallel among historic eruptions. More than that it would raise some fundamental questions concerning the nature of volcanism in general. Recognizing this situation, one ought to adopt the simpler hypothesis if it is at all possible to bring the facts into harmony with it. We shall begin, therefore, by marshalling the facts which support this view.

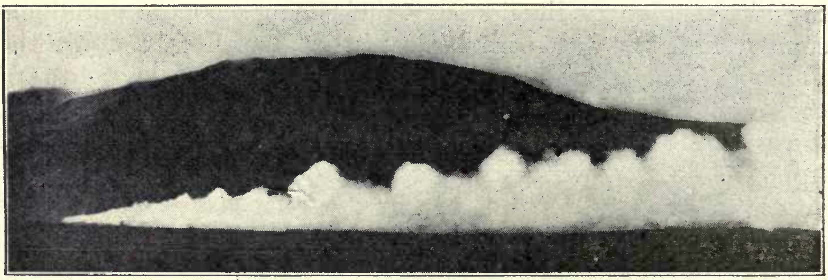
The very position of the smokes, in the bottom of a valley, suggests at once the likelihood of their being secondary products emanating from a stream of lava that has flowed down the Valley. If there had been any notable flow of lava toward the Bering Sea in connection with the eruption of Katmai, it would certainly have occupied a position not far different from the activity with which we are dealing. Truly volcanic vents, on the other hand, are in the great majority of cases situated on mountain tops rather than in valleys, although there is nothing to prevent their bursting through the floor of a valley.

### PRACTICALLY ALL SURFACE WATER EVAPORATED IN THE HOT VALLEY.

The surface water hypothesis finds its strongest support in the indubitable fact that practically no water drains out of the Valley into the streams below. It is situated in a region of unusually heavy rainfall; half a dozen glaciers discharge their streams into it; and there are many square miles of snowfields which, during the warm weather of the summer, give forth a large volume of water. Several good sized streams start bravely out from the glaciers into the Valley, but as they course down their hot beds they dwindle until at the end of the Valley their united volumn forms a mud-choked brook only two feet wide and two inches deep. At times this stream probably stops altogether. How unusual this is in this country may be seen by comparing this stream with Martin Creek, whose basin is only half as large and contains no such notable glaciers.

Yet, on a warm day when the snow melt is large, Martin Creek is too big to ford. There can be no question, therefore, but that the greater part of the precipitation that falls in the drainage basin tributary to the Valley is returned to the air by evaporation.

Having ascertained this fact, we set out to see if we could follow the water cycle from precipitation to vaporization. In part this was easy. Whenever rain falls on the hot floor of the Valley it is immediately converted into vapor and returned to the air. During a rainstorm the Valley fairly reeks with the hot steam which is everywhere poured back into the saturated atmosphere. If one investigates the melting snowdrifts which fringe the Valley, he finds innumerable trickling rills



*Photograph by R. F. Griggs*

A BIG VENT FAR DOWN THE VALLEY.

The man silhouetted against the steam gives the scale, but only part of the steam column is shown, illustrating the magnitude of the vents which must be accounted for. This volcano is located 8 miles from Novarupta, where the activity of the Valley reaches its climax.

which start down from them, but they soon suffer the same fate as the pattering raindrops. Before they have crossed many yards of the hot earth, their waters become warm and dry up without having the opportunity to unite into a stream large enough to furnish water for a fumarole of any size. The larger streams likewise shrink so gradually that one cannot find a notable diminution in their volume in any particular place; that is to say, the vapor from their waters is given off diffusely along their whole length. When one considers the very large areas of the Valley where the ground stands at a temperature approximating the boiling point, it will be seen that its surface has the capacity of evaporating an enormous volume of water in addition to the great volumes of steam which come up from the specialized vents.

### BIG VENTS NOT DUE TO DIFFUSE SURFACE EVAPORATION.

But such diffuse evaporation could not give rise to the great Smokes which give the Valley its character, for in these vents the production of steam is highly concentrated into small areas, where it bursts forth under pressure. To supply sufficient steam for the production of any one of these larger vents would require all the water of a good sized brook, but nowhere can any stream be found which goes up in steam all at once at a particular point. There are several places where a stream runs close beside a good sized vent. In a few places the steam was actually seen boiling up through cold water. But it appears evident on inspection of such places that the steam is quite independent of the brook, which merely happens to run over the orifice by which it finds exit. The brook is not sensibly smaller below such a place. Its temperature is not even measurably altered by the proximity to the hot vapor. (See page 102).

But places where watercourses cross lines of activity are uncommon. For the most part, the position of the vents bears no apparent relation to the streams, but follows a pattern of its own. The waters, seeking their level under gravity, course down through the middle of the Valley. But a great number of the largest vents come out of the marginal fissures which encircle the Valley about 200 feet above its floor. Throughout the Valley the vents are more prevalent along the crests of ridges than in hollows where water would collect. Many of the largest vents are thus located in situations where any great supply of surface water would appear most improbable.

### DO THE SMOKES COME FROM VAPORIZATION OF GROUND WATER?

Such soundings as we were able to make in the throats of the vents confirm the view that they are more deep-seated than the surface drainage, for we could find no bottom with a stone tied to a hundred foot rope. This made it at once clear that they could not be formed by the vaporization of the surface streams. Perhaps they may come from the vaporization of subterranean streams which encounter a hot lava flow at some depth below the present surface. This supposition, it must be admitted, is wholly hypothetical since there is not otherwise

any reason for suspecting the presence of such streams. Neither in the Valley itself nor in the country round about does one meet with evidences of underground water in any volume. It is a sandstone country whose strata, whenever exposed, appear unusually dry. No springs have been found, except in glacial or landslide debris. Since this view cannot be supported with evidence, it will be advisable to defer its consideration until some other aspects of the problem, concerning which there are more tangible data, may be taken up.

*Photograph by R. F. Griggs*

THE RIVER LETHE CROSSING A LINE OF FUMAROLES.

The steam in places actually bubbles up through the cold water. The volcanoes and the surface drainage manifestly have no connection with each other.

In the first place it will be advisable to consider the magnitude of the phenomena to be accounted for. The number of vents mounts up, literally, to several millions. Of these there are several hundred whose steam columns trail along before the constant wind for over a mile. (See page 100).

Many of these come forth from throats several feet in diameter. The largest, aside from Novarupta, which is a typical volcano, pours out of a yawning chasm about 20 feet across. Despite the size of the throat, the rush of the

steam is so rapid that it fairly purrs as it comes rolling out. Many of the smokes with smaller throats issue under such pressure as to emit a continuous low-toned roar. In some of them the rush of the emerging steam is so rapid that a pebble tossed into them is either immediately spewed out again or sinks slowly down against the rushing current of rising steam. The supply of water necessary to maintain a constant flow of steam of such dimensions is, of course, considerable. Multiplied by the number of the big vents, it becomes enormous. Now, the visible surface water which is dissipated by diffuse evaporation appears to be great enough in volume to account for practically all of the drainage from the water-shed tributary to the Valley. One who sought to establish the presence of underground streams of sufficient size to produce the smokes observed would have considerable difficulty, therefore, in finding a source for such a quantity of water.

### NO LAVA FLOW TO VAPORIZE GROUND WATER.

If the smokes are due to the vaporization of surface or ground water by a mass of hot lava poured out on the ground at the time of the eruption, it should be easy to find the lava flow beneath the fragmental ejecta which cover the surface. But none is to be found. There is absolutely no indication of any lava flow anywhere in the Katmai district other than the ancient basalts of which the volcanoes were built up. In many places deep canyons have been cut by the streams into the surface of the Valley, but nowhere is there the slightest indication of lava beneath. If there were a cooling lava flow close beneath the surface, the bottoms of these narrow canyons, which are 50 to 100 feet deep, (see page 118), should be much hotter than the surface of the ground, but such is not the case. These gorges are like any other part of the Valley. Locally they may be very hot, but these hot spots are always obviously associated with some special vent in the vicinity.

It is not only impossible to find any lava flow, but it is equally difficult to locate any vent from which such a stream might have come. Certainly it could not have come from the crater of Katmai. The low points in its rim are all occupied by glaciers which antedate the eruption, being covered by the same layers of ash as are found everywhere throughout the

district. If any lava flow underlies the Valley, it must have issued from fissures in its floor. Such a fissure eruption is, of course, quite within the bounds of possibility. But we have now reached the stage where, in order to support our surface water hypothesis, we have had to assume the presence of both the lava flow, to be cooled, and the water, to be vaporized. It will now be advisable to consider the other side of the question.

*Photograph by D. B. Church*

THE VALLEY OF TEN THOUSAND SMOKES.

A corner of the Valley of Ten Thousand Smokes, looking from the rim of Novarupta toward Baked Mountain, July 15, 1917.

### SMOKES ARE CONSTANT.

A large body of lava will obviously remain hot for a long time. It would be quite possible for such a mass, if it were present in the Valley, to retain heat enough to continue to send up clouds of steam throughout the six years which have elapsed since the eruption. But it will be recognized that this sort of activity would of necessity be gradually dying out. One should expect, therefore, to find a sensible diminution of the activity of the Valley with the lapse of time. On the contrary no diminution whatever can be detected. The smokes appear exactly the same now as when they were discovered. Compare the pictures above, taken in succeeding years.

The composition of the "smoke" from the vents is another matter of importance in this connection. If the smokes were due to the vaporization of surface water, which had come in contact with hot lava, they should be relatively pure steam. But as a matter of fact these vapors contain a large admixture of acid gases and deposit a great variety of sublimation products, such as sulphur and the two sulphides of arsenic. These

*Photograph by J. D. Sayre*

THE VALLEY OF TEN THOUSAND SMOKES.

Taken from almost the same spot as the picture opposite a year later, July 18, 1918. If anything the activity is greater than the year before. The little fumaroles found emerging from sandstone strata occurred in rocky slopes similar to, but around the corner from, those shown as dark spots on the mountain side in the middle distance.

products, both gaseous and solid, are now in process of analysis by the Geophysical Laboratory of the Carnegie Institution. These analyses, when complete, are expected to be made the subject of a special contribution, and no more than mention of the matter can be made at this time.

### TEMPERATURES ABOVE 400° C.

The temperatures of the vapors are, likewise, matters of significance in this connection. If the smokes were due merely to waters coming in contact with the surface of hot lava, their

temperatures should be in the neighborhood of the boiling point. As a matter of fact, however, all of the more active vents are much hotter than that. They are so hot that when we poked our walking sticks into them they came out blackened and charred from the heat. Once, before we were alive to the situation, we tried to take their temperature with a thermometer

*Photograph by R. F. Griggs*

TAKING THE TEMPERATURE OF A HOT ONE.

Many of the vents were so hot as to be beyond the range of the thermometers we carried the first year; so hot that the steam would char a piece of wood and did not begin to condense for some distance from the orifice. The expedition of 1918 measured temperatures up to 430° C.

tied to a stick. When we took it out, after momentarily plunging it into the hot steam, the string was burned in two, so that we almost lost our thermometer. The smoke emerges at so high a temperature that it is altogether invisible as it leaves the vent, and condenses only after it has travelled some distance through the cold air. (See pictures above). The

vents were so much hotter than we had expected, that in 1917 we were entirely unprepared to measure their temperatures. The expedition of 1918, however, went prepared to cope with the situation. The records thus secured will be given in detail in a paper which is to follow. It may be stated in advance of detailed publication, however, that the temperatures measured ran above 400°C.

In many places the vents occur in lines that very strikingly suggest that their distribution is controlled by the presence of subterranean faults or fissures, which have been concealed by the

*Photograph by R. F. Griggs*

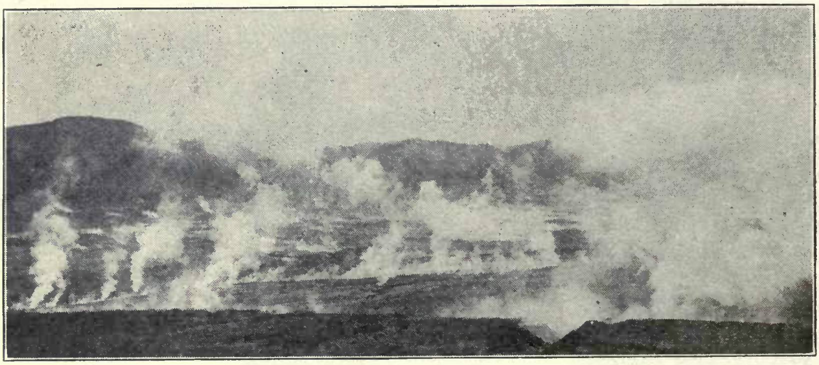
THE SAME VENT FROM A LITTLE DISTANCE.

The steam is so hot that it does not condense until ten feet away from the vent. Some idea of the scale may be gained from the realization that the little steamer enclosed by the circle was our cook stove, shown close up on page 98.

superficial layers of recent ejecta (see pages 108 and 109). In other places they emerge directly from yawning fissures, but the nature of the substratum is such that it is not easy to ascertain whether these correspond with rock fissures or are of a more superficial character. Where the vapor emerges from such wide open faults in the tuff that covers the Valley, it is obvious that these might be merely the superficial avenues of escape from the tuff, rather than the orifices of the true vents.

The linear arrangement in such cases may not be significant, therefore, but when there is no superficial break in the tuff corresponding to the line of smokes, it is difficult to explain their arrangement in any other way than as being outlets of a fundamental fissure in the bed rock. The writer, at least, can imagine no possible means by which such lines of smokes, often more than a mile in length, could be explained on the surface water hypothesis.

But although the volume of the emanations, their chemical character, their temperatures and their arrangement all give very clear and positive indications that they are true volcanoes,



*Photograph by R. F. Griggs*

LINES OF FUMAROLES ACROSS THE VALLEY.

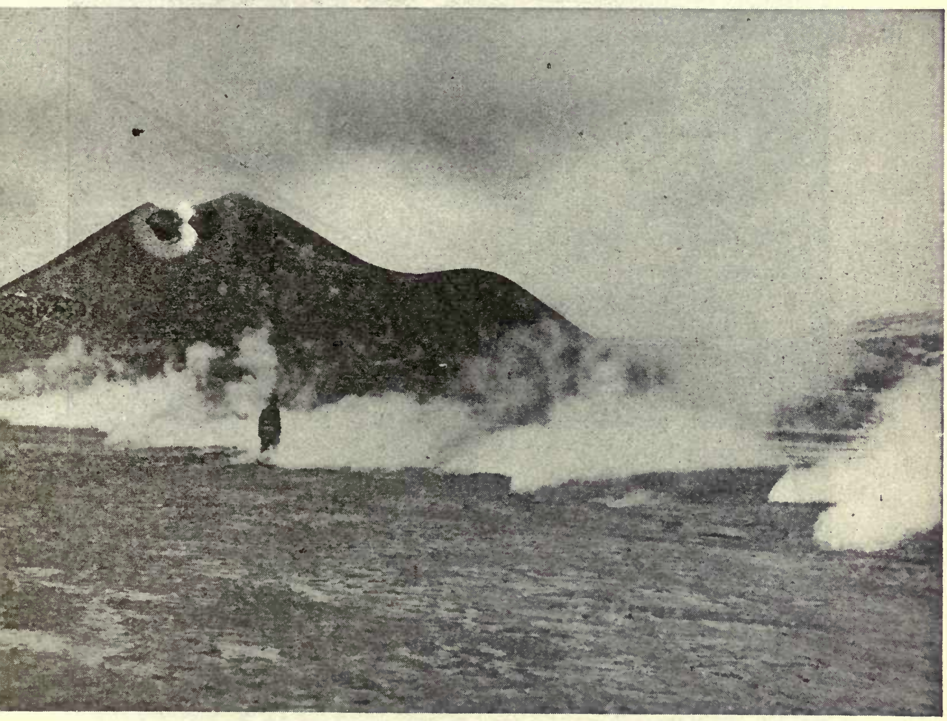
A portion of the valley floor where the linear arrangement of the fumaroles is very conspicuous, indicating that they spring from fissures traversing its floor or encircling its edges.

we were very unwilling to consider the matter settled until we could find ocular evidence of their actual emergence from orifices in the bed rock underlying the Valley.

But this proved to be a matter of considerable difficulty, for the Valley is everywhere filled with a very thick deposit of the peculiar tuff which is discussed in the succeeding paper. There was good reason to believe, as will be seen, that the smokes did not originate in the tuff itself, but it so plasters up the Valley that it is difficult to ascertain the character of the ground from which they do emerge. As we prosecuted the exploration, therefore, we were constantly on the watch for evidence which would throw light on the source of the vapors.

FUMAROLES EMERGING FROM SANDSTONE STRATA.

Finally, far down toward the end of the Valley, we found a considerable area from which this tuff had been removed by erosion. In the bluffs of tuff still standing along the edges of this bare area, we found some sections where the whole length of the throat of a burned out fumarole had been exposed.

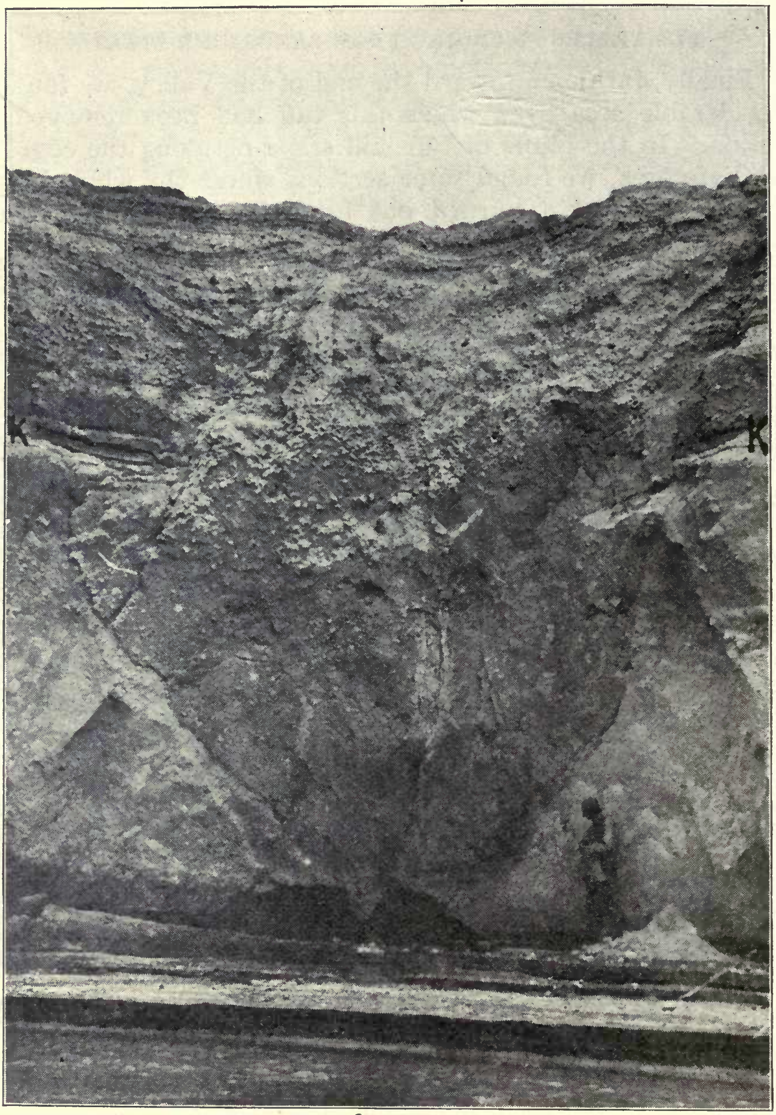


*Photograph by J. W. Shipley*

A NEARER VIEW OF A LINE OF FUMAROLES.

There is no surface indication of fracture. They probably spring from a deep-seated fissure.

These conduits ran clear down through the tuff to the bed rock beneath. (See page 110). At another place, we found a deposit on the surface of the bed rock which looked like that from an old fumarole, having apparently been formed by continued action of the fumarole after the erosion of the overlying tuff. We were not, however, satisfied with such evidence of burned out fumaroles, for there is always the possibility of misinterpret-




*Photograph by R. F. Griggs*

A FILLED CRATER IN THE MUD FLOW.

The crater was formed in the mud flow by explosive action originating below the base of the section, which here rests on undisturbed sandstone strata exposed by the stream in the foreground. This crater stood open during the explosion of Katmai, whose three-layered ash, marked K, may be plainly seen on the top of the original mud surface. Later there came a secondary flow of mud which filled up the crater and piled up about ten feet above the surface of the primary flow. The fill did not, however, choke off the fumarole which for some time maintained an open vent to the surface, shown in the photograph by a faint vertical streak rising from the bottom of the crater.

ing the character of such deposits. We were not willing to adopt so important a hypothesis unless we could find conclusive proof of its correctness. We were the more cautious in this matter because the underlying rock was not lava nor igneous rock of any kind, but sedimentary sandstone strata, as could be clearly seen in the bed of the adjacent stream.

Early in the exploration we observed the numerous fumaroles that come out of the upper slopes of Falling Mountain (see page 112). But since these occur in an ancient volcanic mass it was not certain that they could rightly be considered similar to the vents of the Valley.

Our uncertainties continued, therefore, until finally on the Broken Mountains, which are surrounded on all sides by the active vents of the Valley, we came upon several groups of small fumaroles which set at rest all possible doubts. They were located on almost precipitous slopes, (see page 105), from which all loose ejecta had slumped away, leaving the bed rock exposed to view. Here there could be absolutely no question, for the *little fumaroles were coming directly from the sandstone strata*, emerging from the crevices in the rocks which lay evenly bedded in undisturbed layers as originally deposited. The little crevices through which they found their way out had no doubt been broken open by the general disturbance, which so thoroughly broke up these mountains as to have suggested their name. But at these particular places the eruption had shattered the rock so little as not to disturb the position or arrangement of the original strata.

It is, of course, quite unnecessary to add that such fumaroles could not originate in the sandstone, but must have come from some mass of intruded magma beneath the surface. The very smallness of these little fumaroles made them all the more significant, for if these little wisps of steam were proven to come out from beneath the bed rock, the great columns of vapor in the adjacent Valley must as certainly draw their energy from the interior of the earth.

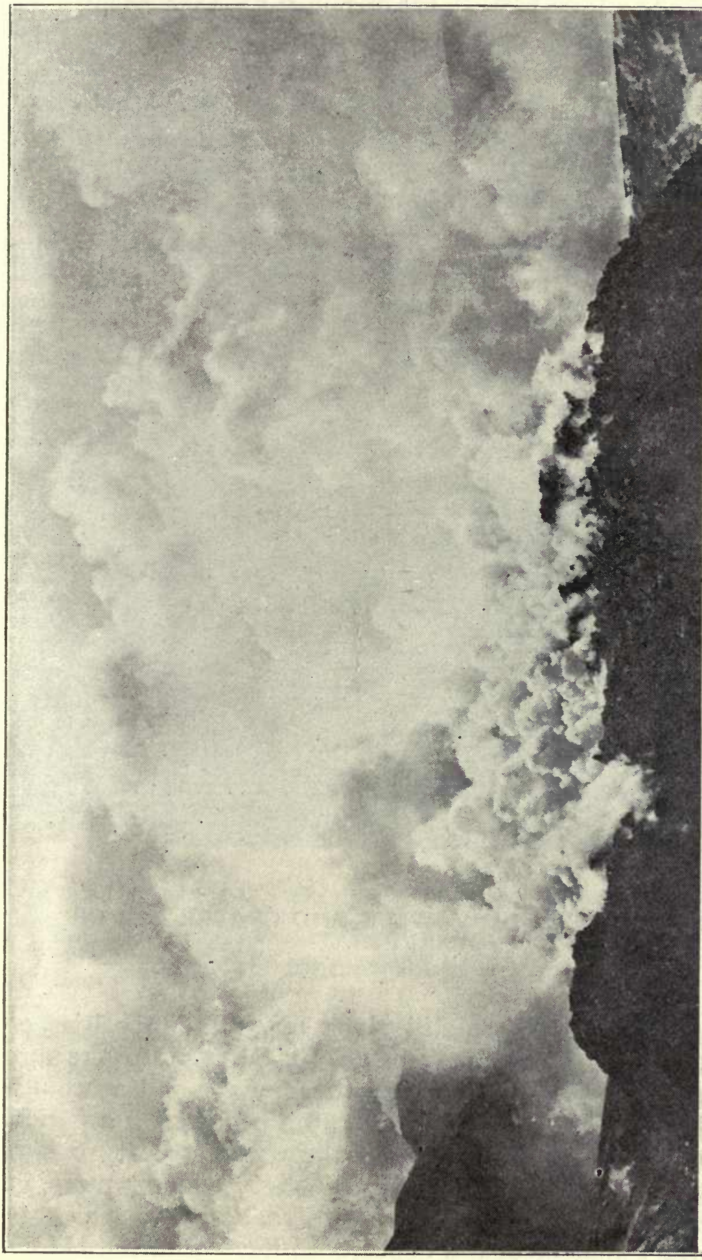
## MAGMA REACHED SURFACE IN NOVARUPTA VOLCANO.

The magma that must thus underlie the whole of the Valley comes to the surface at one point—the crater of Novarupta (see pages 112, 113 and 114). This vent, which is in every way a typical volcano, has burst through the floor of the Valley like

*Photograph by P. R. Hagelbarger*

THE CRATER OF NOVARUPTA FROM THE HIGH POINT OF ITS RIM.

This volcano differs from the other vents of the Valley in that the lava here came to the surface, forming the plug which fills the throat. In the distance is Falling Mountain with numerous fissures issuing from crevices in ancient lava high above the Valley floor.



*Photograph by R. F. Griggs*

THE LAVA PLUG OF NOVARUPTA FROM THE CRATER RIM.

In the background at the sides may be seen the encircling wall of the crater.

the other smokes by which it is surrounded. Like them it is an absolutely new volcano, having burst forth in a situation where no volcanic activity had ever previously occurred. Its crater, which is 0.8 mile (1.25 km.) in diameter, is occupied by a plug of cooling lava that recalls the remarkable "spine" of Mt. Pelee. This plug is, however, much less conspicuous, being much broader, 800 ft., (250 m.) than high, 200 ft., (60 m.)

*Photograph by P. R. Hagelbarger*

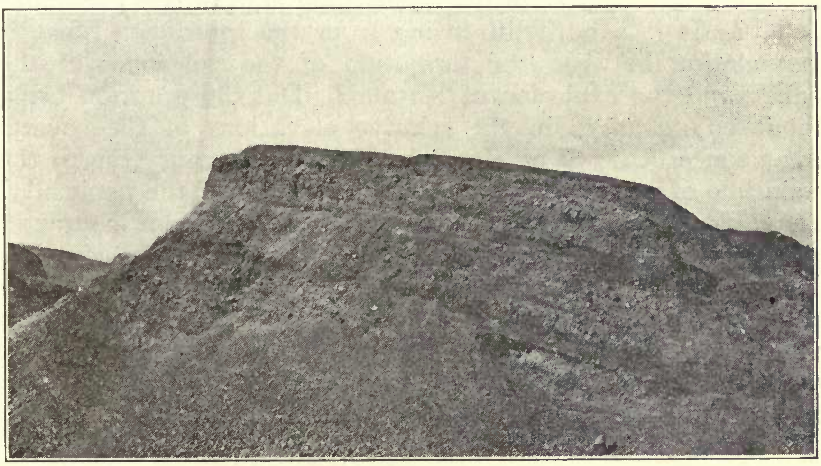
DETAIL FROM THE LARVA PLUG AND CRATER RIM OF NOVARUPTA.

The broken pile of lava is about 200 feet high.

From this plug of lava are still given off great quantities of gases which in calm weather ascend 10,000 ft. into the air, forming great clouds that obscure the sky for miles around (see page 113). The history of Novarupta began with a period of explosive activity, during which it threw out a great mass of ash and pumice, forming deposits 50 feet thick or more in the vicinity of the vent. This explosive activity, which is shown by the sequence of the deposits to have occurred before that of Katmai, was much less violent than that of its greater

neighbor, as may be judged from (a) the larger size of the cinders thrown out; (b) the greater depth of the deposits immediately around the vent, (see cut below); (c) their lesser distribution, for they cannot be identified beyond a few miles from the volcano. At the close of this explosive period a conspicuous crater ring was thrown up around the vent. This was followed by the gradual extrusion of the lava plug.

Concerning the size, condition, and geological relations of the other portions of the mass of subterranean magma, we are of course, left entirely to speculation. There are the best of



*Photograph by R. F. Griggs*

A FAULT SCARP ON BROKEN MOUNTAIN.

The man gives the scale. This is the same fissure as that shown in the distance on page 98. The visible face of the scarp is composed of stratified ash, mostly from Novarupta. The sequence of the ash strata shows that Novarupta burst forth before the explosion of Katmai, but this faulting occurred after the eruption.

reasons for supposing that it approaches closely to the surface over the whole area of the Valley, and over Katmai Pass as far as Observation Mountain as well, for over all of this area there is clear evidence of fumarole action. The sections through the tuff described above, which gave us our first intimation that the steam might reach the surface through the sandstone, were almost at the very foot of the Valley, 13 miles from Novarupta. Some of the largest and hottest of all the volcanoes, e. g., that pictured on page 100, occur far down toward the foot

of the Valley, indicating as definite a connection with the subterranean magma at that point as in the upper Valley, where large vents are more numerous. The whole area, thus giving evidence of the near approach of the magma to the surface, is 20 miles (32 km.) in length, 9 miles (14.5 km.) in greatest breadth and covers an area of 53 square miles, (137 sq. km.).

The recognition of the fact that the Valley is truly volcanic inevitably raises some questions of great interest and importance. What are the geological relations of the magma beneath? What are the reasons for its bursting through in this particular Valley? Is it a batholith rising from the interior? What is the relation between the formation of the volcanoes of the Valley and the explosion of Katmai? Did the eruption bring about any changes in the relative elevations of the several areas concerned? Why does the Valley run transverse to the main line of volcanoes which follows the axis of the peninsula? These and other fundamental questions of similar character open most fascinating problems for future study. If, as seems possible, some of them can be solved, the study of the Valley of Ten Thousand Smokes will have taken us several steps nearer the solution of the greater problem of volcanism and its relation to diastrophism. But we are not yet in a position to attempt the discussion of these matters.

Scientific Results of the Katmai Expeditions of the National Geographic Society.

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# III. THE GREAT HOT MUD FLOW OF THE VALLEY OF TEN THOUSAND SMOKES.*

Robert F. Griggs.

As we explored the Valley of Ten Thousand Smokes, the first thing that attracted our attention, when we could look beyond the smokes themselves, was a curious line that encircled the Valley almost like the high water mark of a flood. Above this line were the ordinary gray ash slopes, below it was a great mass of compact hard tuff of a terra cotta color quite different from the ordinary ash.

Examination disclosed the fact that the floor of the Valley is covered with a massive deposit of enormous thickness, which has no counterpart on the surrounding hills. The interpretation of the character and origin of this deposit was, for a long while, our chief problem as we explored the Valley and its branches, for its evident peculiarity at once excited our curiosity.

The difficulty was not that its relations were obscure, for they are so obvious as to suggest the interpretation at first sight. The trouble was that this evident explanation was so seemingly impossible that we were altogether unwilling to accept the testimony of our senses until the evidence became so overwhelming as to eliminate the possibility of further doubt.

Since returning from the field, we have held the matter in reserve, until we could thoroughly digest the evidence and talk it over with some students of volcanism in whose judgment we had confidence. When the matter was first put before these men, it was met with the most violent opposition. They uniformly reacted to the proposition exactly as we had ourselves when we first encountered it in the field. But in the end, when the evidence was presented and all objections answered, without exception they accepted the interpretation as the necessary consequence of the facts.

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I have thus entered into a somewhat personal statement of the matter because I must expect my readers, at least those who have any previous acquaintance with volcanoes, to assume the same attitude and would bespeak in advance their careful consideration to the end, rather than the unceremonious rejection which would otherwise be the fate of the account.

*Photograph by R. F. Griggs*

A CANYON NEARLY 100 FEET DEEP, CUT INTO THE MUD FLOW.

Although this section is located far down the Valley, it shows no indication of the bottom of the mud flow. The thin strata of the Katmai ash may be seen near the top. The figure at the left gives the scale.

I would further add that I am not committed to any theory of the origin of this curious terrane, but will be glad to accept any other interpretation that can be suggested, provided only that it is consistent with the facts as found in the field. Certainly any suggestion that would relieve us of the necessity of postulating an entirely new type of volcanic action will be most welcome.

### VALLEY OF TEN THOUSAND SMOKES FILLED WITH A GREAT DEPOSIT OF TUFF.

Surrounded as it is by high and rugged mountains, the most striking feature of the conformation of the Valley of Ten Thousand Smokes is the flatness of its floor. One could ride a bicycle for miles along its smooth surface, and there are many places between the lines of activity that would be ideal landing fields for airplanes. (See map, page 138).

Where the drainage gullies have gashed this surface, its flatness may be seen to be due to the smooth top of the terra cotta tuff already mentioned. The traveller peers into these canyons in the hope of finding some clue to the thickness of this massive tuff, but in this he is disappointed. In such places one finds cuts of 40, 60, or even 100 feet down into its mass, but none of these, in the upper portion of the valley, reach its base and reveal the character of the formation beneath. This is not only very puzzling, but very impressive as well, for when one finds that it is more than 50 feet thick over wide areas, it becomes evident that the volume of the formation is enormous. Our inability to find any section through it was rendered the more significant by reason of the fact that almost all of the trenches in it are located not in the middle of the Valley, where it might be supposed to be thickest, but along the edges where a minimum thickness would be expected. (See page 118).

The enormous volume of this mass was further emphasized as we extended our exploration through the Valley, for then it became evident that the area covered by it was much greater than had appeared from the head of the Valley. First we found the branch valley heading in the Broken Mountains covered with it. Then we saw the great valley between the Broken Mountains and Knife Peak all filled in the same way, clear back to Novarupta Volcano, forming with the main valley a complete circuit around the Broken Mountains. Finally,

before we came to its extremity, we had reached a distance of 20 miles (32 km.) from the point where we first encountered it back of Observation Mountain, and 15 miles (24 km.) from the divide back of Novarupta Volcano. Altogether it occupies an area of 53 square miles (137 sq. km.). At its highest points, on the divide back of Novarupta and in Katmai Pass, it reaches an altitude of about 3,000 feet, while at the other extremity it extends down to within about 300 feet of sea level.

*Photograph by J. D. Sayre*

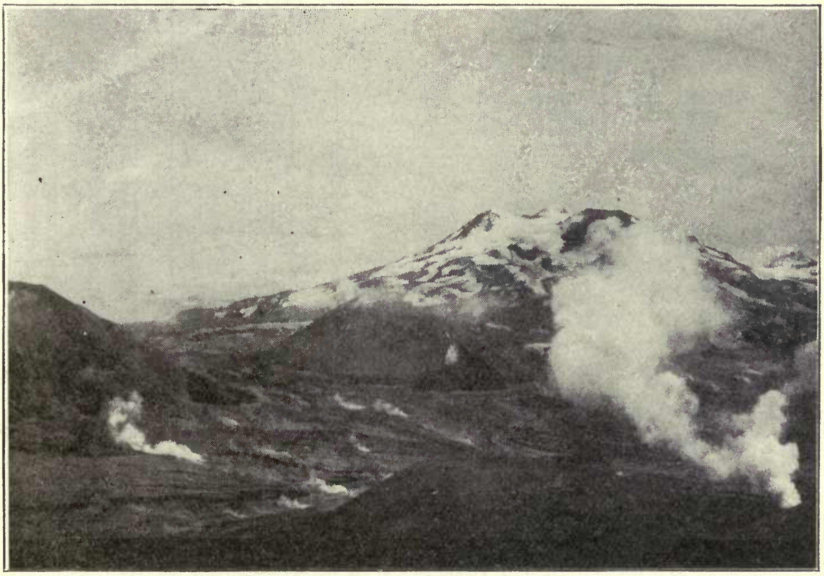
"HOODOO" NEAR FISSURE LAKE.

Characteristic "Hoodoo" weathered out of the solidified mud near Fissure Lake. The stratified ash from Katmai lying on top of the massive mud flow is well shown at both right and left.

Everywhere, in appearance and structure, this formation closely resembles the Katmai mud flow. In color and character the material of the two are of almost identical appearance, being darker and finer than the other ejecta of the recent eruption. They have the same total absence of stratification or of horizontal cleavage planes, contrasting most strongly with the thin beds of the stratified ash. Where cut into by erosion or sheared by faulting, they break with irregular fractures running in any direction with the line of stress. By reason of the character of their cleavage, they are often broken or weath-

ered into the most fantastic blocks, like the hoodoos of the bad land region, (see pages 118 and 120).

The bulk of it is composed of very fine dust-like particles, closely packed together until they form a compact, homogeneous mass. But in this mass are included numerous lumps of pumice and fragments of rock of all sizes, sometimes in large quantities, but always without any trace of sorting or stratification, except where the material was obviously subject to secondary readjustments.

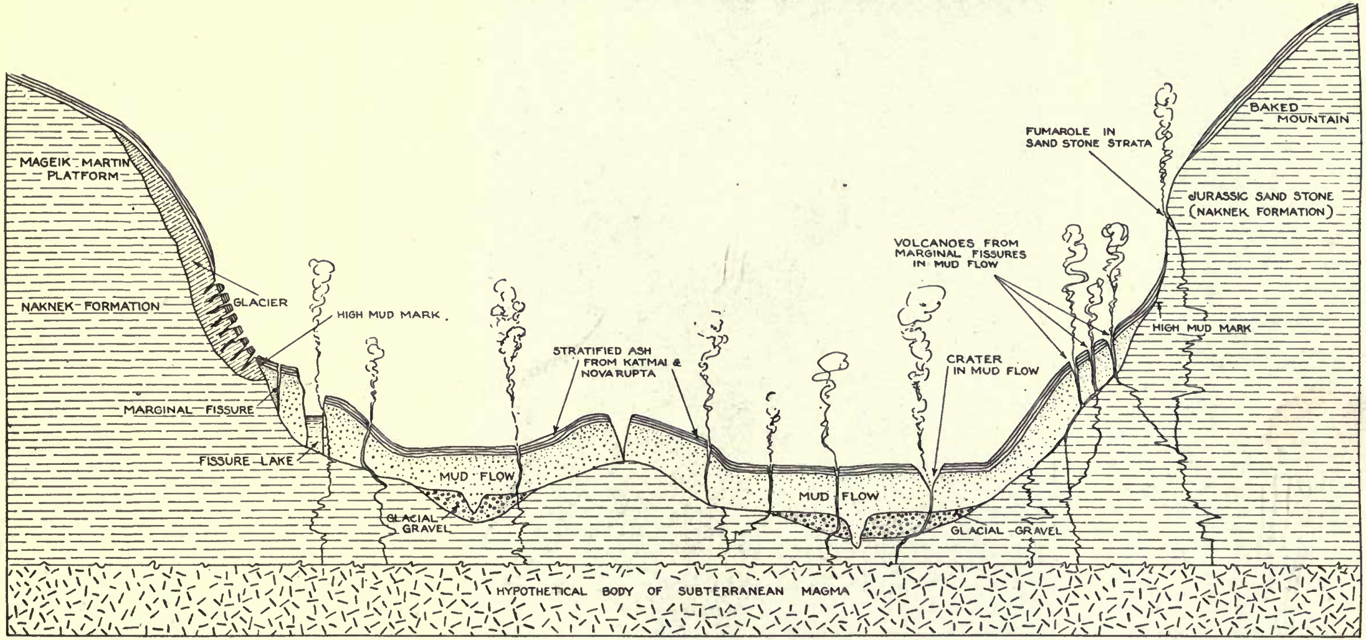


*Photograph by C. F. Maynard*

LOOKING TOWARD KATMAI PASS FROM BAKED MOUNTAIN.
The high mud mark sloping down into the Valley on each side of the mud flow is very evident.

## VALLEY SURROUNDED BY A CONSPICUOUS "HIGH WATER MARK."

The "high water mark," separating the chocolate tuff-covered basin of the Valley from the gray ash slopes of the mountains before alluded to, impresses one more and more as he studies the phenomenon. It follows, in a general way, a contour line 200 to 360 feet above the floor of the Valley. While it thus reminds one of the shore line of a pond, it is obviously




A GENERALIZED SECTION OF THE VALLEY OF TEN THOUSAND SMOKES.

Taken approximately on a line connecting the summits of Knife Peak and Mt. Martin. For the sake of compactness sections of the branches of the valley between Baked Mountain and Knife Peak are omitted, although they also were filled by the mud flow and contain many active volcanoes. The thickness of the mud flow and all data indicated below the surface of the ground are, of course, purely hypothetical.

not precisely level like the shore of a lake, but is subject to variations in level so large as to be easily discernible to the eye without the use of instruments; as though the Valley had been filled with a heavy, viscous fluid like tar, which, as it flowed down the Valley, had succeeded only imperfectly in finding its level. The most conspicuous example of this is in the southwest corner of the Valley under the glaciers of Mageik, where the "high water mark" is more than a hundred feet lower than further east along the foot of Mount Cerberus. But the same departure from a precise level appears in many other places. (See pages 121, 130 and 136).

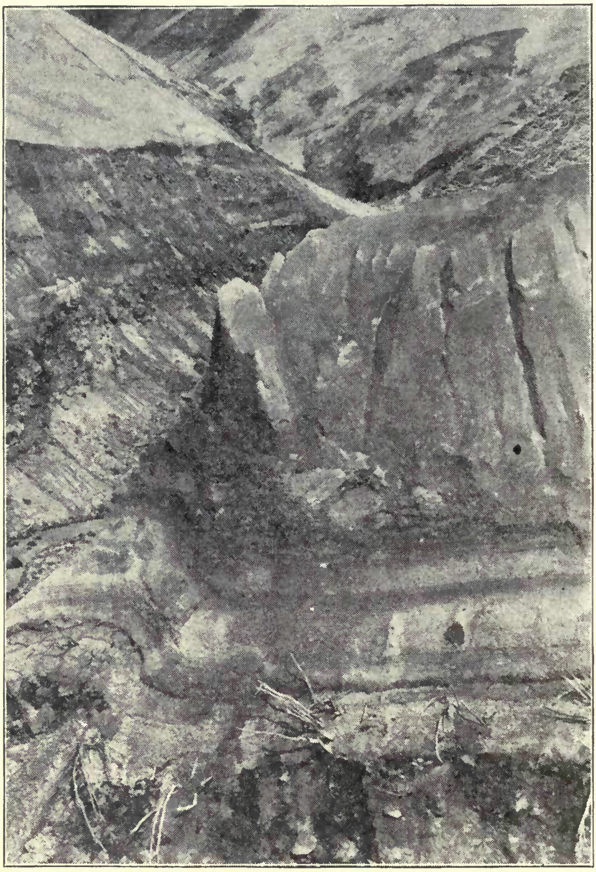
All around the margin of the Valley, just below the "high water mark," runs a series of gaping fissures, as though the surface had been stretched by subsidence after its formation. Conditions remind one of a temporary puddle which, after having frozen over heavily during a rise in a river, is drained again so as to let the ice down onto the bottom with consequent stretching and cracking all along the shore. The analogy is carried further by the criss-cross cracks, which run in all directions across the surface like the contraction cracks in a frozen pond. (See page 108). Where the ridges from the shoulders of the mountains project into the Valley, the marginal fissures coalesce and run far out into the Valley in just such a Y form as do the ice cracks at the point of a peninsula in our drained pond. In another place, where there was apparently a considerable detached hill in the floor of the original valley, there remains a high area whose crest is occupied by a notable fissure, just such as occurs when the ice is let down over a similar hump in the bottom of a pond. (See page 122).

About ten miles down the Valley there is a distinct horizontal line of the same red material a hundred feet above the present "high water mark," just as though the liquid that filled the Valley, standing for a little while at this higher level, had "frozen" a little along the bank before subsiding.

The reader may perhaps wonder by this time why, when there were such clear indications that this was a mud flow, we had any hesitancy in calling it such at once. But to us, as we worked in the field, the reason was evident enough. By no hypothesis that we could invent were we able to suggest a source of the material.

### TUFF OF VALLEY SIMILAR TO KATMAI MUD FLOW, BUT FORMED BEFORE THE EXPLOSION.

There was no such difficulty in the case of the Katmai Mud Flow, for in the last spasms of the eruption great quantities of finely divided mud were thrown out on top of the coarse ash and pumice deposited in the earlier stages of the eruption. Part of this, wetted up perhaps by the heavy rains that followed the eruption, slumped down off the ash covered slopes into a



*Photograph by D. B. Church*

A SECTION OF THE KATMAI MUD FLOW.

Contrast with the section of the Great Mud Flow given on page 132. Here the mud flow occurred after the ashfall which lies beneath it on the original surface of the ground whose irregularities the strata follow. The bushes show no sign of burning, either here or where they protrude through the mud flow. Stratified ash here fifteen feet thick.

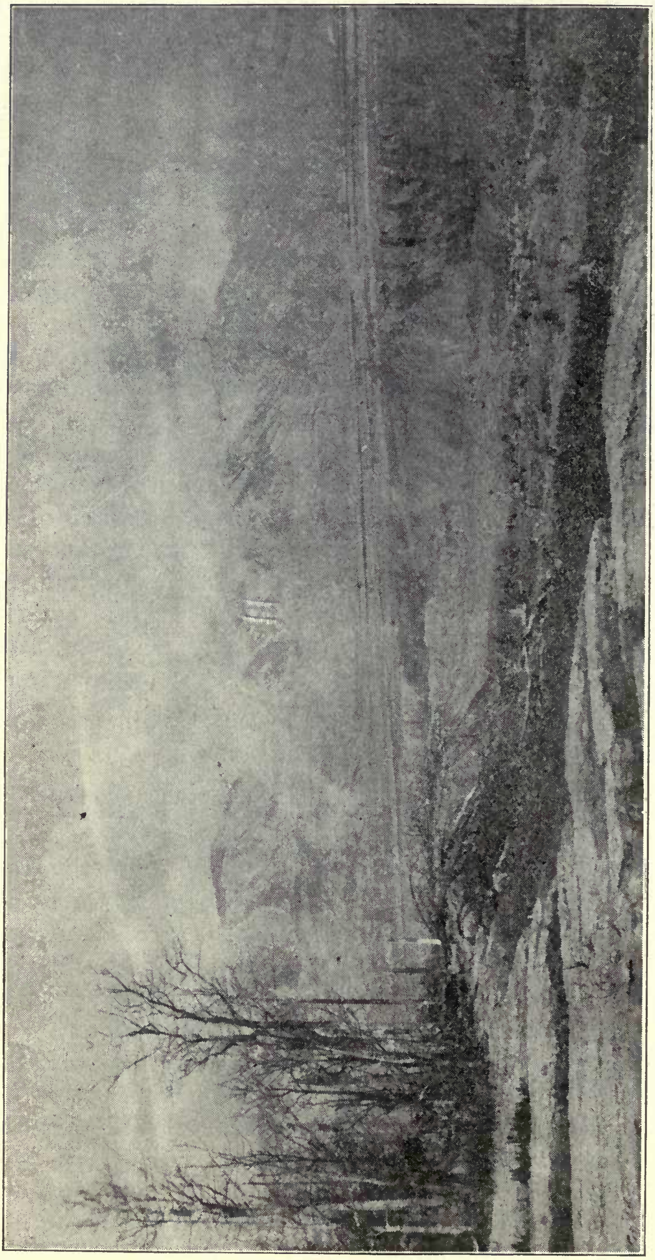
narrow gulch at the foot of the mountain. Material from a large area was thus gathered together into relatively restricted compass, forming a notable deposit many feet in thickness and over two miles long. Although there were no eye witnesses of the Katmai Mud Flow, there is the best of proof that it occurred after the eruption, and probably in the manner stated, for the upper slopes of Katmai are still plastered with mud like that which slumped off, and the mud flowed down over the stratified ash, which is everywhere found beneath the mud flow, showing clearly that the latter occurred after the ashfall. (See page 124).

But in the Valley of Ten Thousand Smokes conditions are reversed, for the great mass of tuff which forms its floor is everywhere overlain by the stratified ash from Katmai, (see pages 110, 118, 120, 132, 136 and 140), proving that it must have been in position at the time of the ashfall. When it was realized that the great mass of tuff in the Valley had originated before the ashfall, its interpretation became more of a puzzle than ever, for everything indicated that it was no ancient formation, but belonged to the present eruption. Mud flows of the type of that formed on Mt. Katmai have frequently occurred after eruptions, but nothing like this, occurring as a preliminary to an eruption, is described in the literature with which we are familiar.

## TUFF OF THE VALLEY HAS NO COUNTERPART ON THE SURROUNDING MOUNTAINS.

In view of these anomalous conditions, we felt that to adopt the hypothesis that the tuff of the Valley was a mud flow would raise more problems than it would solve. Such a supposition appeared, therefore, of little value in interpreting the Valley. We were left for a long while, therefore, without any hypothesis whatever to account for what we saw.

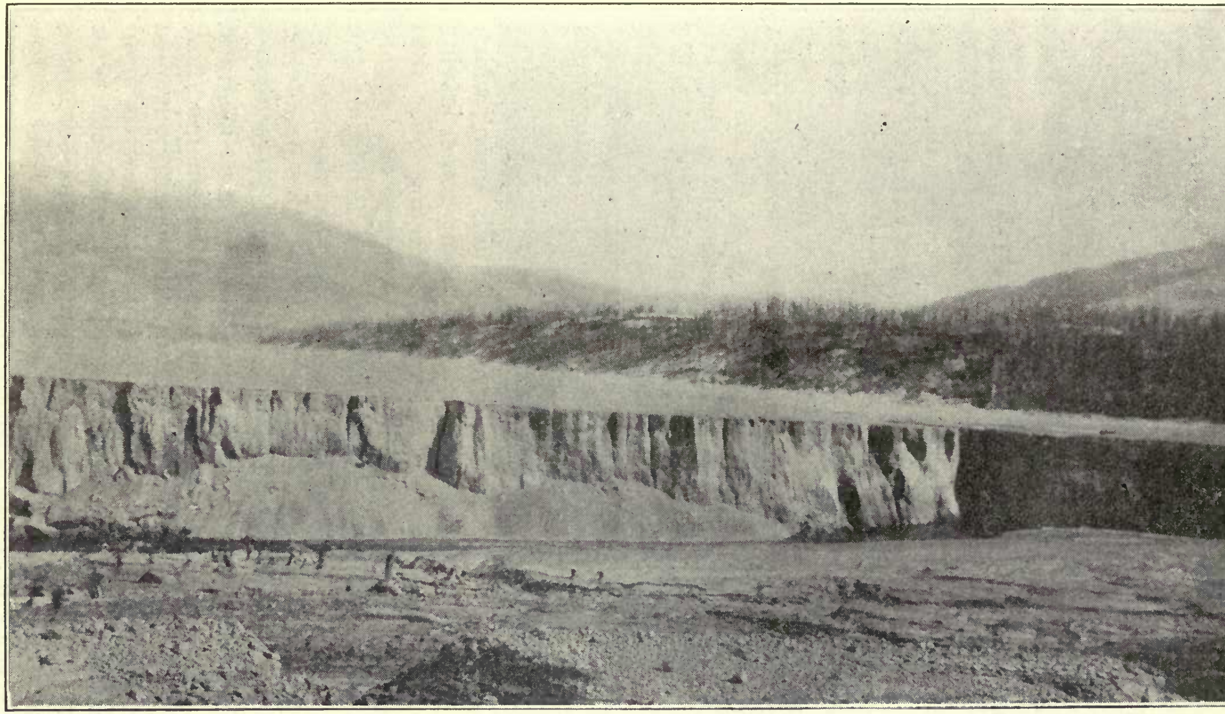
Nevertheless, detailed examination of the surrounding mountains confirmed the suggestion of the "high water mark"—that the tuff was confined to the floor of the Valley—for it had absolutely no counterpart on the slopes above. They were everywhere clothed with the same strata of ash as covered the tuff itself. This stratified ash always rested directly on the original surface of the ground—bed rock or old soil as the case might be, without the slightest indication of anything corresponding to the massive deposit in the Valley.



*Photograph by P. R. Hagelbarger*

LOOKING UP THE MUD FLOW ALONG ITS EDGE.

At the left, undisturbed forest above the high mud mark; in the center the charred stumps of trees, that were burned off by the mud, exposed by later erosion.



*Photograph by P. R. Hagelbarger*

LOOKING ACROSS THE MUD FLOW NEAR ITS TERMINUS.

Nearly panoramic with the picture on the opposite page. At the left, stumps of burned trees exposed by erosion. In the distance, the undisturbed forest above the high mud mark. The layers of Katmai ash may be made out as a line across the face of the bluff below the forest, between primary and secondary mud flows.

### ENGULFED TREES SHOW THAT THE TUFF MUST HAVE ORIGINATED AS A FLOW OF MUD.

Finally, when our work carried us down the Valley toward Naknek Lake, we found conditions, which, while rather adding to the anomalies already puzzling us than explaining them, yet gave such clear cut and positive evidence of the mode of deposition of the tuff as to make its character certain.

In the lower Valley, where the remains of the former forest still persist to tell the tale, the "high water mark," or as it had better be called the "high mud mark," becomes even more conspicuous and significant than it is in the upper Valley. Whatever our doubts may have been before, no matter how great the difficulties of explanation that remained, one glance at the remains of the forest embedded in this tuff was all that was needed to convince everyone that we were dealing with a gigantic mud flow. Right down to the edge of the erstwhile mud the trees stand undisturbed, but below that level they are overriden, twisted and bent before it in such fashion as could not have been done except by a moving liquid. The absolute sharpness of this line separating the uninjured forest from that covered by the moving mud is plainly shown on the photographs reproduced on pages 126, 127, 128 and 136.

At the bend in the Valley, where the forest begins, the mud flow encountered a belt of irregular morainic hills among which it pursued a most irregular course, overtopping some, leaving others standing free above the surface, slopping over into the ravines, and in every way showing that it was once highly liquid. In this vicinity a strong stream, now furnishing the greater part of the water of the Ukak River, was dammed by the mud flow, forming a deep lake. Since the mud flow hardened, the waters of this stream have cut down 20 or 30 feet into this dam, but there still remains a lake a mile long and half a mile wide. Beyond the bend in the Valley the mud flow continued on for more than a mile, gradually thinning out until for some distance back from the tip it is only 10 feet thick, in striking contrast to its great thickness and massive character further up the Valley. Everywhere the mud shows a surprising capacity to adjust itself to the variations in the level of the ground over which it flowed. At one place, near the middle of the level flow, I noticed a tree or two sticking up through the

mud, and upon investigation found that their roots were only about a foot beneath the surface. They had grown on the summit of a morainic hill which, after having been deeply buried, had been almost laid bare again by the readjustment of the mud after the first wave had passed.

But there was none of that evidence of violent damage which would have accompanied the rush of a flood of water down the Valley. Although the bushes were bent and twisted

*Photograph by R. F. Griggs*

THE EDGE OF THE MUD FLOW.

The burned and broken remnants of the trees below the high mud mark stand in strong contrast to the undisturbed forest which, though killed by the eruption, was beyond the reach of the mud.

beneath its weight, they were not broken nor uprooted as they would have been if the heavy mud had rushed upon them at a high speed.

### EVERY STICK BURIED BY MUD FLOW REDUCED TO CHARCOAL.

Near the edge of the mud flow a few trees remained sticking up out of the mud. When we took hold of these we found to our astonishment that they had been burned off a foot beneath the surface. Later, in sections where the flow had been cut into by erosion, we found that every particle of wood that had been buried by the mud had been turned to charcoal. In some places we found the mat of old tundra vegetation, transformed

into a thin sheet of charcoal, lying between the mud flow and the old surface of the ground. Some of the trees engulfed had been a foot in diameter, but they were as completely charred as the fine twigs. (See pages 126, 127, 129, 132, 133 and 134).

Upon finding this evidence that the flow had consisted of hot mud, we began to wonder whether the Katmai Mud Flow had likewise had a high temperature. It was with great interest, therefore, that we awaited an opportunity to examine the Katmai Flow again to see if we had overlooked evidence of

*Photograph by J. W. Shipley*

ACROSS THE MUD FLOW NEAR THE LOWER END.

The bare surface of the mud contrasting with the forested slopes beyond and the definite level of the opposite edge are characteristic. The mounds in the middle of the flow are small fumaroles which have caught and cemented together piles of the ash blown before the wind.

such a character. But when we re-examined it, we found that in this respect it was altogether different from the Great Mud Flow. The wood which it had buried was as white and clean as though bleached in the sun. Its mud had been cold, therefore, just as would be expected of mud soaked up by excessive rains.

It was now fully proven that the tuff lying on the Valley floor was a mud flow of stupendous proportions, but this certainty, instead of settling our problems, had raised a host of new questions more puzzling than the original ones. The fact that it had completed its course down the Valley before the ashfall, by removing the possibility of its having come from the

blowout of Mt. Katmai, made it more difficult than ever to find the source of the material. The high temperature which characterized the moving mud definitely put it into a different class from the Katmai Mud Flow. And the freshness of the plant remains and other features combined to fix its date as immediately prior to the explosion of Katmai.

### MUD FLOW VERY DIFFERENT FROM A LAVA FLOW.

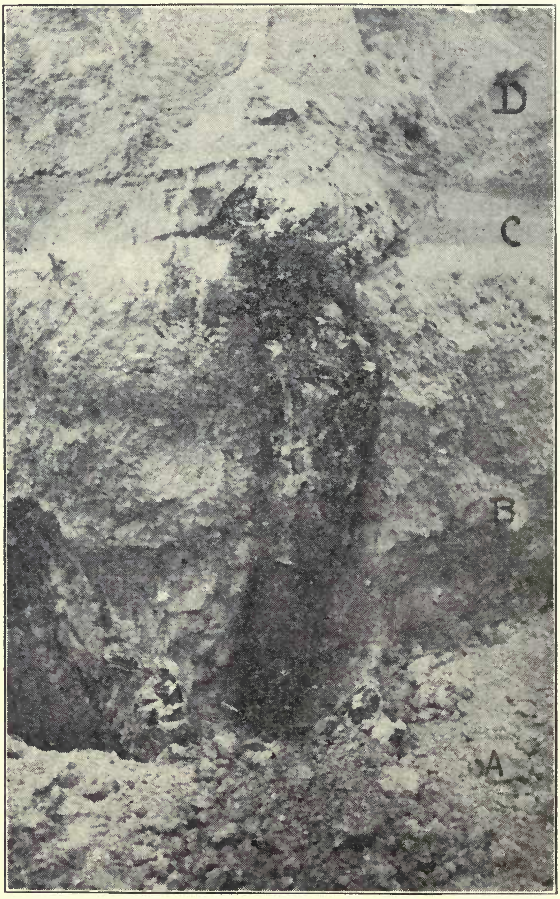
One way out of these difficulties at once suggested itself. If we could consider this formation a lava flow rather than a mud flow, its explanation would be easy, for a lava flow of such dimensions would be nothing remarkable. But lava comes from a mass of molten magma which solidifies into crystalline rock. By no stretch of the meaning of the term can this tuff be considered crystalline rock. It is composed of fragmental materials like the ash that settles out of the air. Although compacted into a firm mass, somewhat resistant to the weather, it crumbles to powder between one's fingers. Though hot by human standards of comparison, its temperature was far below the melting point of any lava, for, although it reduced the trees which it engulfed to charcoal, it did not, at least in the lower Valley, set fire to the forest above the high mud mark, nor even consume the trees that were not completely covered up. On the contrary, the projecting parts of the burned trees were sound and untouched by fire. Where cooled by the atmosphere, or by the underlying soil, the mud had evidently lost its heat before charring was complete, for the stumps were not burned clear to the ground and good sized branches were charred through only when buried a foot beneath its surface. This indicates that the charring was a gradual process rather than any sudden combustion, such as breaks forth when a lava flow pours through a forest. (See page 133).

### ATTEMPTS TO EXPLAIN IT AS A MUD FLOW OF THE USUAL TYPE.

When it thus became evident that our flow of hot mud could not be considered a lava flow, the most probable explanation seemed to lie in interpreting it as a mud flow of the conventional kind, formed from the ejecta of some previous eruption. Such a hypothesis would of course leave its temperature unaccounted for, if indeed it were not inconsistent with the observed temperature relations; but if its other features

could be accounted for on such an assumption, its high temperature might perhaps be explained by some subsidiary hypothesis.

If the mud flow were thus the product of a previous eruption, it would be expected to have been formed immediately after that eruption, like the Katmai Mud Flow, before the mass of mud had had time to dry up and "set." For, once such a mass of mud dries out, it would not be likely to be soaked up




*Photograph by L. G. Folsom*

A STREAM CUT SECTION NEAR THE TOE OF THE MUD FLOW.

The engulfed tree is completely reduced to charcoal. The section shows (a) piles of debris lying on the original surface of the ground; (b) the unstratified mass of the mud flow; (c) the three layers of the ash from Katmai; (d) a mass of secondary outwash deposited by the stream which later cut the section. The wash of this stream broke off the part of the tree protruding above the mud flow.

again en masse in such a manner as to permit the formation of such a tremendous quantity of mud all at once. Indeed, I can imagine no process of nature by which the present hardened tuff could be changed back into liquid mud.

But the condition of the burned trees is unequivocal proof of the recent date of the mud flow. It occurred so recently that there has been no time for the protruding parts of trees to decay since they were killed. Even the small twigs of the dead trees are still in place, giving positive evidence that the

*Photograph by R. F. Griggs*

STUMPS OF TREES BURNED OFF BY THE MUD FLOW.

Exposed by later erosion. It is to be observed that the mud was so cooled by contact with the soil that it did not burn the stumps clear to the ground. The roots protected by a few inches of soil were not burned at all.

mud flow must have occurred very recently, (see pages 126 and 129). There is everywhere a conformity between the mud flow and the overlying ashfall that of itself negatives the possibility of an interval of erosion between them. There are, moreover, occasional evidences that the mud was still fresh and liquid at the time of the ashfall. There are a number of places where local adjustments of the mud occurred after the ashfall. In such situations a secondary flow of mud lies above the layers of ash, (see pages 110, 136 and 140). All lines of evidence thus converge to show that the mud flow occurred immediately before the explosion of Katmai.

### NO OLD MATERIAL FROM WHICH MUD FLOW COULD HAVE BEEN FORMED.

If, therefore, this mud flow is to be interpreted as a secondary deposit produced by the working over of the original ejecta of some previous eruption, it will be necessary to suppose that some of the preliminary events of the present eruption, such, perhaps, as the melting of a large quantity of snow, occurred in such a way as to soak up a mass of old mud lying on the mountains and start it down into the Valley. With this possibility in mind, we searched the mountains for some

*Photograph by R. F. Griggs*

MAT OF VEGETATION REDUCED TO CHARCOAL BENEATH THE MUD FLOW.

The original surface of the soil has been uncovered by erosion.

remnants of an ancient stratum of mud. But not the slightest indication of any such deposit could be found. It was our custom to examine and measure sections, cut by streams through the layers of ash, wherever found. In all the sections examined the ash from Katmai lay directly on bed rock or old soil as the case might be, with no such mud deposit intervening. Yet it would be altogether impossible for every trace of so extensive a deposit to have been turned into mud and carried into the Valley. Any deposit thrown into the air from a crater would be spread, in small quantities at least, over a

great expanse of country. The mud that gave rise to the relatively insignificant Katmai Mud Flow is recognizable as a distinct stratum on top of the rest of the ashfall over all of the mainland country as far away as the seashore. The mass of the mud in the Great Mud Flow is so many times greater than this that traces of the antecedant bed from which it came would certainly have been found somewhere, if it was produced in a manner at all resembling the mud of the Katmai Flow.

The only geologist who ever visited the district, before the eruption, was J. E. Spurr, who in 1898 crossed Katmai Pass, traversing both Katmai Valley and what is now the Valley of Ten Thousand Smokes, then an ordinary grass covered valley. His account makes no mention of any deposit of fragmental volcanic material of any sort. Since the discovery of the mud flow I have had the opportunity of talking the matter over with Mr. Spurr, who stated, in the most positive terms, that there was no such deposit along his trail. And, as will be shown below, the distribution and slopes of the mud flow are such that part of it must have originated in Katmai Pass, which he crossed. But let us assume, for the sake of the argument, that a deposit of the mass and character requisite for the formation of the mud flow was actually present before the eruption, even though no trace of it has been found by any of the parties that have explored the district.

### NO DRAINAGE AREA FROM WHICH IT COULD HAVE BEEN CONCENTRATED.

Such an assumption immediately raises one of the difficulties that confronted us in our first efforts to find a source for the mud of the Valley. The area of the broad Valley is so great, in proportion to the steep slopes of the surrounding mountains, that there is no tributary drainage area around its upper end large enough to have served as a collecting ground from which the mud could have come. The mud flow thus covers almost half of the drainage area from which it could have come. Its area is 53 square miles, while that of the whole basin is only 110 square miles. If these mountain sides supplied the material that now covers the Valley, they must have been everywhere covered to a depth approximately equivalent to the present thickness of the tuff of the Valley, i. e., at least 50 feet. This is

*Photograph by J. D. Sayre*

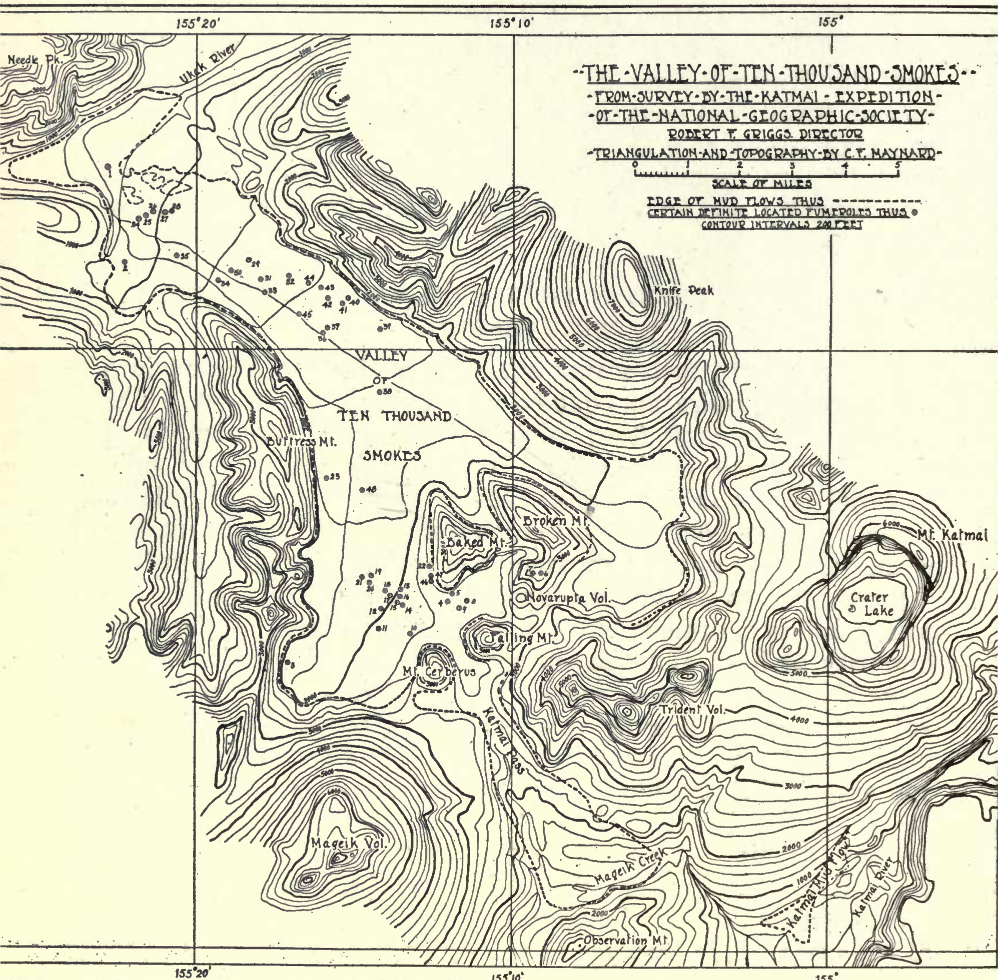
A CANYON ERODED IN THE MUD FLOW NEAR ITS TERMINUS.

The high mud mark and the undisturbed forest above it well shown at the right. In the bluff below the forest, the line formed by ash from Katmai may be made out between primary and secondary flows of mud.

on the impossible assumption that the whole of every slope tributary to the Valley furnished its share of the mud. Whereas it is manifest, from its gravitational relations and the position of the high mud marks, that the mud could by no chance have come from more than a small fraction of the watershed, (7 square miles). The contrast between the Great Mud Flow and the Katmai Mud Flow in this matter is very striking indeed, for in that case the collecting ground, (5 square miles), was eight times as great as the area at present covered by the mud, (0.6 square miles). See map, page 138. But let us waive this difficulty and go on with the consideration of the situation assumed.

### NO WATER SUFFICIENT TO LIQUIFY THE MUD IF THE MATERIAL WERE PRESENT.

To transform such a vast quantity of dry tuff or dust into mud would require an equally vast quantity of water. The volume of the mud flow, while not accurately known, is of the order of one cubic mile. To hold this quantity of solid material in suspension would require at least a cubic mile of water. Where could it have come from? The only possibility is that the heat of the approaching eruption might have melted a great mass of ice and so furnished the requisite water. To melt such an enormous block of ice would require a stupendous quantity of heat, but the energy of the erupting volcano was probably many times more than sufficient for this. The volcanoes are so heavily covered with glaciers that it is not improbable that there may be a cubic mile of ice on their drainage area. The trouble is that the volcanoes are still ice-clad at the present time. There is no indication of their having carried within recent geological time larger glaciers than those that still cover their flanks. They bear as many and as large glaciers as their inactive neighbors east and west. One of the remarkable features of the eruption was its small effect on the glaciers of the Volcanoes. There are two miles of ice cliff in the rim of Katmai crater, remnants of glaciers which were beheaded, but not melted, by the eruption. The remains of these glaciers cover every hollow in the mountain. The most extensive of them all stretches down into the Valley of Ten Thousand Smokes, where it meets the mud flow. Mageik, likewise, has a notable snowcap which extends up to and around


THE VALLEY OF TEN THOUSAND SMOKES
FROM SURVEY BY THE KATMAI EXPEDITION
OF THE NATIONAL GEOGRAPHIC SOCIETY
ROBERT F. GRIGGS DIRECTOR
TRIANGULATION AND TOPOGRAPHY BY C. F. MAYNARD
SCALE OF MILES
EDGE OF MUD FLOWS THUS
CERTAIN DEFINITE LOCATED FUMEROLES THUS
CONTOUR INTERVALS 200 FEET
155°20'
155°10'
155°
Needle Pk.
Ukak River
Knife Peak
VALLEY
OF
TEN THOUSAND
SMOKES
Buttress Mt.
Broken Mt.
Baked Mt.
Novarupta Vol.
Falling Mt.
Mt. Cerberus
Mt. Katmai
Crater Lake
Trident Vol.
Katmai Pass
Mageik Vol.
Mageik Creek
Observation Mt.
Katmai River

the crater. Its glaciers are still, as Spurr described them, the most extensive in the district. Two of them come down into the Valley of Ten Thousand Smokes where their tips were apparently melted by the mud flow as it ran across them, but they show no sign of having otherwise contributed to it.

If the eruption had caused any wholesale melting of glaciers, not only should the bare hollows they formerly occupied be evident, but the water thus released should have caused tremendous floods on both sides of the range, for it is hardly conceivable that all of the ice melted could have been in a single locality, and that the whole of the water so formed could have been taken up by the mud. But the only floods, of which there is any evidence, occurred long after the eruption and were due to other causes.

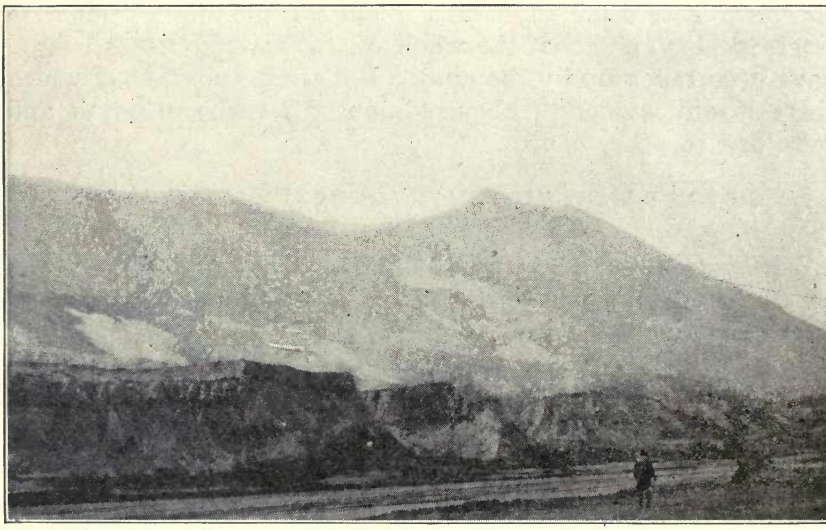
### HOT MUD FLOW MUST HAVE COME FROM INTERIOR OF THE EARTH.

*Although it has been made clear that the mud could not well have come down from the mountains, one of the most important evidences of that fact has not yet been discussed. The high mud mark has been mentioned as one of the most conspicuous features of the Valley. It was clearly produced, like a high water mark, by the mud rising against the sides of the Valley. It would not be developed at any point where mud flowed into the Valley from the mountains above. It should, therefore, be easy to recognize the source of the mud by the absence of high mud marks at any point where it may have entered the Valley. But an examination of the circumference of the mud flow shows that the high mud mark is continuous, for it can be clearly followed around the whole of the mud flow, except in the vicinity of Novarupta Volcano, where the great thickness of the overlying ash deposit obscures the relation of the deeper layers. This can only mean that the mud welled up from within the Valley itself.* (See map, page 138.)

Our search for its source had to be transferred, therefore, from the surrounding mountains to the Valley floor. The broad smooth floor of the Valley, although broken by the thousands of fissures and craters from which issue its millions of volcanoes, shows no orifices that give any particular evidence of having been the source of the mud. The only thing to guide us in our search was the slope of the high mud marks, for since the mud flowed down the valley under gravity it must have originated, in part at least, near the highest points that it covered.

PROBABLY ERUPTED FROM SEVERAL FISSURES.

From this fact it becomes at once evident that it could not have come from a single orifice, for there are two distinct summits from each of which it flowed in both directions. One of these is Katmai Pass, the other is in the vicinity of Novarupta Volcano. The altitude of both is in the neighborhood of 3,000 feet. From Katmai Pass the mud flow not only reaches into the Valley of Ten Thousand Smokes, but extends down the



*Photograph by D. B. Church*

PART OF THE MUD FLOW ACROSS THE PASS FROM THE VALLEY.
Looking toward Observation Mountain from the upper flat of Mageik Creek. The layers of Katmai ash covered by a secondary flow are plainly shown in the bluff, two-thirds of the way up.

valley of Mageik Creek to the foot of Observation Mountain, against which it accumulated to a thickness of 30 or 40 feet. (See picture above).

Novarupta, although situated in the floor of the Valley, is located near a col which separates the two arms of the Valley that encircle the Broken Mountains. On the west side of this col the surface of the mud flow descends till it joins the branch coming down from the Pass at an altitude of about 2300 feet, then continues its descent across the front of Cerberus and Mageik down the main valley to the terminus of the flow,

a hundred feet above sea level. From the east side of the divide the mud flow slopes gently down around the foot, first of Mt. Katmai and then of Knife Peak, till it joins the main valley below the Broken Mountains.

It is clear that, so far as its gravitational relations are concerned, the mud flow could be accounted for by assuming two points of extrusion at these two summits, but the evidence furnishes no reason for excluding the participation of other vents at any point along the line of the flow. Around Novarupta the mud flow has the appearance of being extraordinarily massive, as though a great quantity of it had welled up from that vent. But the appearance of Katmai Pass gives the contrary impression, for there the depth of the flow is slight and there is nothing to indicate that there was ever any great accumulation at that point. Inasmuch as there is clear evidence of fumarole action since the eruption, on both sides of the Pass, it appears more probable that the mud in this vicinity welled out of a number of fissures at different levels, rather than from a single large vent at the summit.

There is no evidence of any of the specific vents from which the mud may have come. If, as is supposed, they were merely fissures in the floor of the Valley, lying below the level of the flow, one would not expect to find them any more than he can locate the unseen springs which feed many a lake. They may be the same as some of the fissures from which the Smokes of the Valley are at present issuing, or they may be stopped up with their own product, the present volcanoes coming from new fissures opened since the mud flow.

### NO EVIDENCE THAT IT ORIGINATED IN EXPLOSIVE ACTION.

Since the mud resembles a fragmental product, it might be supposed that it originated in explosive action, but, however this may be, there is no evidence of explosions violent enough to have thrown it out against the mountains round about, for, as already pointed out, it is confined to the Valley. So far as there is evidence of its origin, therefore, the indications are that it welled quietly up out of the bowels of the earth.

It is clearly recognized that current theories of volcanic action do not provide any means of explaining the formation of any such mud flow as we have found in this Valley of Ten

Thousand Smokes. Nor have I any hypothesis to suggest to account for the mechanism of its formation. This has long held me back from reporting its occurrence. But the evidence that it actually did occur seems perfectly clear and conclusive. Under the circumstances, therefore, there was nothing to do but to report the facts as they were found in the field.

It is proper to add, however, that a reading of the descriptions of other eruptions, in the light of what we have found in the Valley of Ten Thousand Smokes, indicates that the extrusion of such masses of hot mud may not be so much a unique as a neglected aspect of volcanism. But a discussion of such phenomena lies beyond the scope of the present paper, which is concerned merely with recording the phenomena of the Valley of Ten Thousand Smokes.

In the discussion of this remarkable terrane we have set down numerous considerations which would be quite superfluous if it were located in a district more accessible to geologists, so absolutely clear are its major relations. But, recognizing that under present circumstances it would not be practicable for all geologists who might be skeptical to go and see it for themselves, we have tried to supply the answers to all the questions likely to arise in the minds of such skeptics. Since the district has been set aside as a National Monument, however, it is to be hoped that it will not for long remain so inaccessible, but that its remarkable features may be seen and studied by many other observers within a very few years.

Scientific Results of the Katmai Expeditions of the National Geographic Society.

# IV. THE CHARACTER OF THE ERUPTION AS INDICATED BY ITS EFFECTS ON NEARBY VEGETATION.*

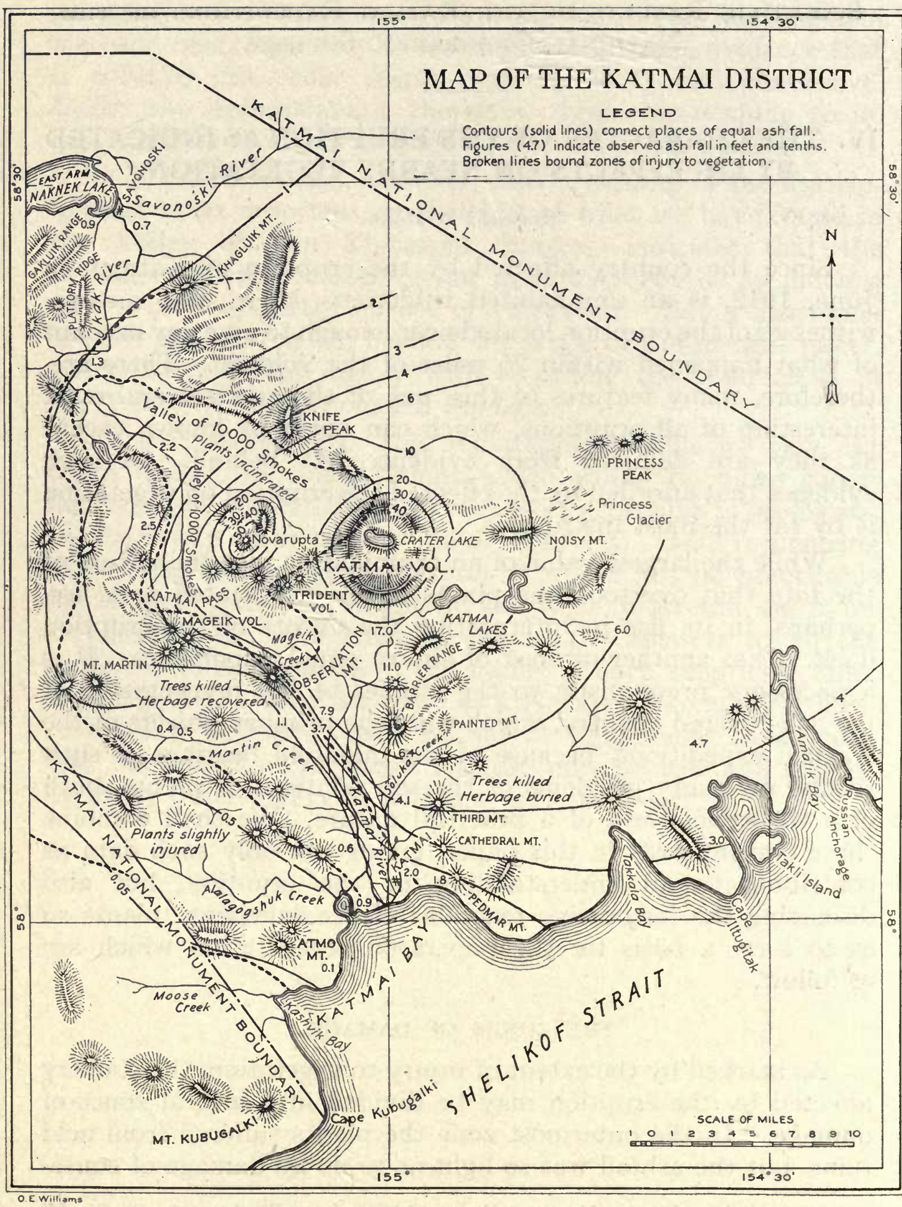
Robert F. Griggs.

Since the country affected by the eruption of Katmai, in June, 1912, is an uninhabited wilderness, there were no eye-witnesses of the eruption located near enough to give any account of what happened within 25 miles of the volcano. There are, therefore, many features of this, one of the greatest and most interesting of all eruptions, which can never be known except as they are deduced from evidence left behind. Of such evidence that afforded by the effect of the eruption on vegetation is by far the most instructive.

While the largest value of an examination into the nature of the fate that overtook the plants of the devastated area lies, perhaps, in its use in interpreting the events of the eruption itself, it has another interest of almost equal importance. It is a necessary prerequisite to the studies of the revegetation of the ash-covered country, which were the primary objects of the Katmai expeditions, because of the manifold bearings of such studies on many problems of the soil relations of plants, both of a theoretical and of a practical nature. We shall combine these two interests in this paper, giving not only such data as contribute to an understanding of the eruption, but also discussing the restorative reactions of the surviving plants so as to form a basis for the papers on revegetation which are to follow.

## THE ZONES OF DAMAGE.

As marked by the extent of injury to vegetation, the country affected by the eruption may be divided into several zones of damage. In the outermost zone the plants suffered from acid rains, but the ashfall was so light as to do no damage of conse-


MAP OF THE KATMAI DISTRICT
LEGEND
Contours (solid lines) connect places of equal ash fall.
Figures (4.7) indicate observed ash fall in feet and tenths.
Broken lines bound zones of injury to vegetation.
155°
154° 30'
58° 30'
58°
KATMAI NATIONAL MONUMENT BOUNDARY
EAST ARM NAKNEK LAKE
SAVONOSKI
Savonoski River
GAKLUIK RANGE
PLATFORM RIDGE
Ikak River
IKHAGLUIK MT.
KNIFE PEAK
Valley of 10000 Smokes
Plants incinerated
Novarupta
CRATER LAKE
KATMAI VOL.
TRIDENT VOL.
KATMAI PASS
MAGEIK VOL.
Mageik Creek
MT. MARTIN
OBSERVATION MT.
Trees killed
Herbage recovered
BARRIER RANGE
KATMAI LAKES
PRINCESS PEAK
Princess Glacier
NOISY MT.
PAINTED MT.
Soluka Creek
Martin Creek
Trees killed
Herbage buried
THIRD MT.
CATHEDRAL MT.
Plants slightly injured
Katmai River
Alalagogshuk Creek
PEDMAR MT.
ATMO MT.
Moose Creek
KATMAI BAY
Kashvik Bay
Cape Kubugalki
MT. KUBUGALKI
SHELIKOF STRAIT
Takkala Bay
Cape Ilugitak
Takli Island
Amalik Bay
Russian Anchorage
N
SCALE OF MILES
O. E. Williams

quence. In the second zone, covering parts of Kodiak and Afognak Islands, the ashfall was so heavy as to do great damage to the smaller plants, but the trees and bushes that protruded were comparatively unaffected. The third zone includes those areas of slighter injury on the mainland. In the fourth zone the trees and bushes were killed but the grass has come back without permanent injury. In the fifth zone not only were the trees killed, but the ashfall was so heavy that the herbage as well was destroyed except where the ground was later cleared. In the sixth zone every vestige of life was consumed by fire, leaving the country absolutely sterile. The areas covered by these zones are shown by the map given herewith. (See page 174). It will be observed that they are not concentric belts lying one inside the other, but are to a considerable extent independent, occupying different sectors of the area around the volcano. Because of the geographical peculiarities of the country, moreover, they intergrade very little, at least in those areas so far explored, but are rather sharply separated from each other by definite geographical boundaries.

### OUTLYING AREAS INJURED BY ACID RAINS.

On account of the unsettled condition of the country affected, and particularly because the interests of the scanty population are not agricultural, the damage to plants at great distances from the volcano was a matter of very much less concern than it would have been in a populous agricultural country. Observations of damage to plants were therefore never recorded at all in many cases, and where published were simply printed as news items in the local papers. The records are, therefore, much scattered and difficult to secure, but it should not be supposed on this account that damage to vegetation in the outermost zone was insignificant in amount.

At La Touche in Prince William Sound, some 300 miles east of the volcano, Mr. F. R. Van Campen, then superintendent of the mines, in a private letter, states that following the eruption the rain was so acidulated by the fumes as to cause stinging burns wherever it touched the flesh. He had his chemist analyze this rain and found that the trouble was caused by sulphuric acid which was present in considerable quantity. Unfortunately the analysis giving the precise concentration of the acid has been lost. This acid rain did serious injury to the

leaves of the native perennial vegetation, in some cases causing defoliation. But to the cultivated annuals of the gardens it was so injurious as to cause their complete destruction.

The magnitude of this feature of the eruption can be better envisaged if one imagine the volcano located in New York City, in which case crops would be destroyed as far away as Pittsburgh, Portland, (Maine), and Richmond, (Virginia). It would not be fair to suppose, however, that in such a hypothetical eruption all crops would be destroyed within the area indicated, for the occurrence of such acid rains is sporadic, being dependent both on the drift of the fumes under the wind and on the occurrence of the atmospheric conditions necessary to produce precipitation at the time when the acid laden clouds were passing over the given area.

The effects of the eruption on vegetation in the vicinity of Kodiak, which is typical of the second zone where the ashfall was so heavy as to smother all of the smaller plants, have been discussed in earlier papers and require no amplification here.[1-2-3]

Conditions in the third zone, comprising the outlying fringes beyond the areas of greater destruction on the mainland, may be best described after consideration of the inner zones.

### TREES KILLED IN AREAS OF LITTLE ASHFALL.

The fourth zone, where trees and bushes were killed, although the ashfall was so light as not to destroy the herbage, occupies an area of about 666 square miles lying to the south, west, and north of the volcano, beginning with the west side of Katmai Valley and extending around the Valley of Ten Thousand Smokes into the unexplored country to the northeast of the volcano. The position of this zone is determined by the fact that the west wind which blew during the eruption carried the ash cloud off in the direction of Kodiak, so that much of the area relatively close to the volcano was only lightly covered with ash. (See map, page 174.)

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[1] Rigg, Geo. B. The Effects of the Katmai Eruption on Marine Vegetation. Science II. 40: 509-513. 1914.

[2] Griggs, Robert F. The Effect of the Eruption of Katmai on Land Vegetation. Bull. Am. Geogr. Soc. 47: 193-203. Figs. 1-10. 1915.

[3] ———, ————. Scientific Results of the Katmai Expeditions. I. The Recovery of Vegetation at Kodiak. OHIO JOURNAL OF SCIENCE. 19: 1-57. Figs. 1-34. 1918. Includes a digest of literature pertinent to the present paper.

The present condition of the vegetation throughout this zone is shown by the pictures on page 178. The trees and bushes are dead or, toward the edge of the zone and in somewhat sheltered places, have here and there a tuft of leaves where a bud survived. Beneath the trees the ground is covered with a rank growth of herbage. The effect of the ashfall here was the same as at Kodiak—namely, to destroy the weaker plants, giving increased opportunity for the strong growing survivals.

Along the west side of Katmai Valley where the ashfall was from 6 to 12 inches, the present herbage is an almost pure stand of grass—*Calamagrostis langsdorfii.* In the Valley of Martin Creek, which was much more lightly covered with ash, there is a considerable variety of other plants beside the grass. In Ukak Valley, where the ashfall exceeded a foot, all these were killed and the present ground cover is horsetail—*Equisetum arvense.* This plant grows here in a luxuriance quite unmatched elsewhere, covering mile on mile of country in pure stand. The plants reach a size about double that usually attained by this species, being fully waist high over large areas. (See page 178.)

The matter of greatest interest to be discussed in connection with this zone is, however, the cause of the death of the trees.

### WERE THERE HOT BLASTS IN THE ERUPTION?

It is clear enough on the face of it that the death of these trees cannot be accounted for by the ashfall. Over much of this zone the ashfall is six inches or less, as compared with a foot at Kodiak where the trees were not perceptibly injured.

In view of this situation our first inquiry was as to whether Katmai had given forth such hot blasts as characterized many other eruptions, notably those of Pelee and Taal. It may be stated very positively that there is no evidence whatever of any blasts of such tornadic violence as have occurred in many cases. No uprooted trees or other similar evidence of high winds radiating from the crater are to be found. The absence of evidence does not, however, furnish conclusive proof that such blasts did not occur.

The havoc wrought by other agencies was quite sufficient to cover up evidence of tornadoes of hot gas, which in a lesser eruption would have left tremendous devastation in their wake. The ashfall around the crater of Taal, for example, is reported as

*Photograph by J. W. Shipley*

THE TRAIL THROUGH THE TALL GRASS ALONG THE WEST BANK OF KATMAI RIVER.

Representative of conditions in the fourth zone where the trees were killed but the ashfall was so light that the grass quickly recovered.

*Photograph by R. F. Griggs*

HORSETAIL WAIST DEEP IN THE DEAD FOREST OF UKAK VALLEY

The ashfall was here about two feet deep, sufficient to smother the grass and all other geophilous plants except *Equisetum arvense*, which covers the hillsides for miles in unparalleled luxuriance.

only 8 to 12 inches,[4] while at Katmai it was 40 feet on the crater rim and 15 feet at a distance of five miles. The flat flood plain of Katmai Valley with its forest of large trees is the place which should have shown the most definite evidence of hot tornadoes. But this was swept by a terrific flood which so tore up the dead forest as to cover up any lesser damage which may have preceded it. Nevertheless it must be noted that the trees are still standing everywhere throughout the Valley, except in areas swept bare by the flood. On the other hand, while violent hot blasts like those that devastated St. Pierre have not been known to retain their power for great distances from the vent, the dead trees under discussion were some of them situated as much as 25 miles away.

But, while there is no evidence of hot blasts of tornadic violence, it is difficult to imagine such widespread destruction as we are dealing with as due to other causes than withering blasts from the volcano, and there is considerable evidence that these were the agents of destruction. Those trees that survived in areas of otherwise complete destruction were invariably so situated as to be sheltered from winds coming from the direction of the crater.

In lower Katmai Valley, which bends so that the east side is sheltered from the volcano while the west side is exposed toward it, all trees were killed on the exposed west side and in the middle of the valley, but under the protecting mountainsides on the east bank isolated buds on many trees survived. The destructiveness of the eruption was even more mitigated in Soluka Valley, which, although only half as far from the crater, was sheltered by the ridge of the Barrier Range. (See map.) This difference is made the more striking by the fact that while the ashfall was six feet in Soluka Creek it was less than two feet at the east side of Katmai Valley, and less than a foot on the west side where the destruction to trees was greatest.

At Russian Anchorage in the left arm of Amalik Bay, 23 miles from the vent, which the writer visited the year after the eruption, the alders on the mountainsides exposed toward the volcano showed no signs of life while on the opposite sheltered slopes they were green with new leaves. This effect could hardly have been produced except by withering winds from the

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[4] Worcester, D. C. National Geographic Mag. 23 : 359. 1912.

volcano. That the blasts should have retained their power at such distances is the more remarkable because the intervening country is covered with high mountains, which must have offered great obstruction to their passage. So far as the writer is aware, this is the greatest distance which has been recorded as having been reached by volcanic blasts.

If then, it may be considered that the evidence available is sufficient to establish definitely the presence of destructive blasts at distances up to 25 miles from the volcano, it might be argued *a fortiori* how very violent they must have been close to the crater. But it would not be safe to make such an assertion, especially since there appears to have been at least one important difference between these blasts and most of those previously described.

One of the most striking features of the hot blasts from Pelee, Taal and Lassen is the extreme localization of their effects. In each case only a narrow radial sector of the country around the crater was effected, and the edges of this sector were sharply defined.

The most striking feature of the blast from Katmai, on the other hand, is its general distribution around the whole of the circumference of the crater. Not only did it spread in all directions from the crater, but the distance to which it retained its destructiveness was remarkably uniform, being about 25 miles almost everywhere that it has been observed, with little regard to the character of the intervening country. It was almost as destructive at Amalik Bay, across the mountains, as in the Valleys of Katmai and Ukak Rivers which radiate almost directly from the volcano. The only exception to this condition observed was on the southwest, where the destruction of trees was limited by the divide at the head of Martin Creek, which stands somewhat nearer the volcano.

### NATURE OF THE BLAST.

The question of the nature of the devastating blast from the volcano is more difficult to answer from observation so long after the event, but there are a few lines of evidence which may be stated even though it may not be wise to draw positive conclusions. Were poisonous gases given off, or was the destruction due to the high temperature of the blast?

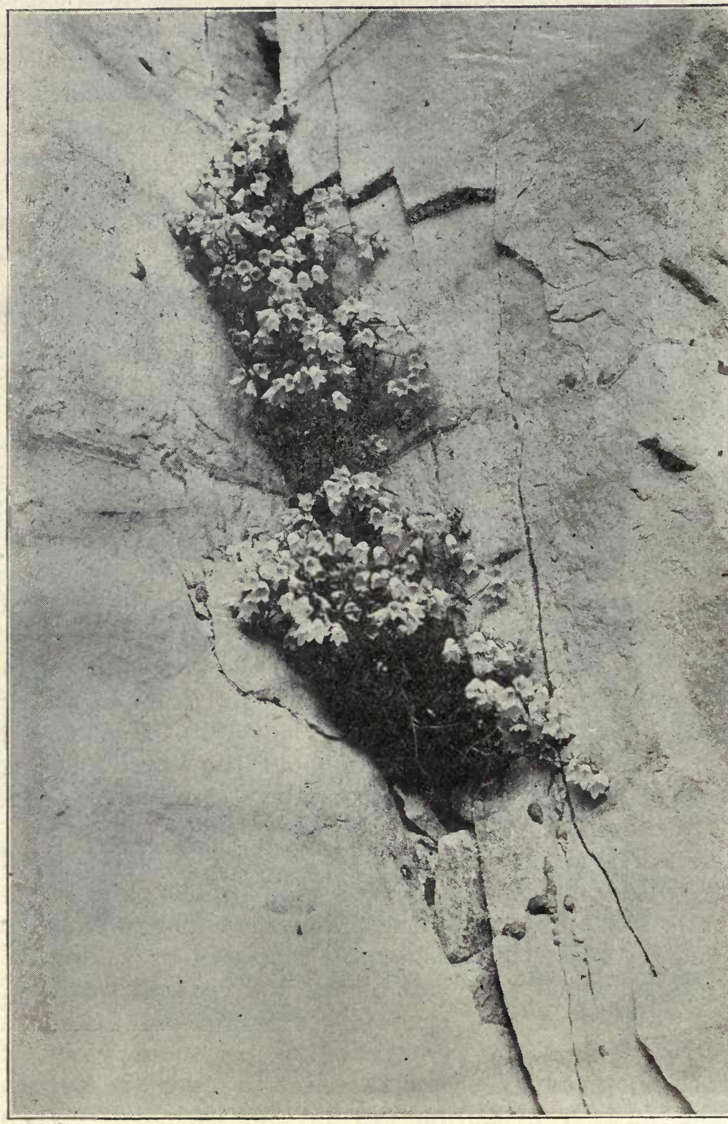
At Kodiak and throughout the area seriously affected there seem to have been sulphur fumes of sufficient concentration to destroy fungous growths, for on our first visit the year following the eruption, all the lichens were found hanging blackened and dead in the trees. Similarly, the natives on the Bering Sea side of the peninsula reported the destruction of the reindeer "moss," with disastrous effects on the herds of caribou that were formerly abundant. Not until four years had passed did living lichens reappear in any quantity at Kodiak. Fungi are, however, very sensitive to sulphur poisoning. The fumes which were sufficient to kill them at Kodiak caused nothing more than temporary discomfort to the people residing in the same district.

Nowhere even close to the volcano itself is there any clear evidence that the seed plants were poisoned by fumes. In many places plants growing in the crevices of the cliffs, although protected from damage from hot air by the cold rocks in which they grew, were so situated that they were fully exposed to the fumes throughout the eruption. Nowhere in such situations did we find the dead remains of poisoned plants. On the contrary, all of the herbaceous plants not covered up by the ash, except those in the fire-swept zone, seem to have gone on flowering and fruiting with undiminished vigor since the eruption. Some of these flowers present most grateful spots of color in a country otherwise totally devastated. (See page 182). Such blooming crevice plants are common throughout the lower and middle portions of Katmai Valley, and numbers of them may also be found in the upper valley close to the volcano.

The survival of three dogs at Katmai Village, noted by Martin, also indicates the absence of poisonous gases in deadly concentration. For, while these animals could probably have survived *hot* blasts of considerable intensity by taking to the native huts, which were half buried and covered with a thick roof of earth and sod, such places would not afford much protection against the penetration of poisonous gases. The evidence, such as it is, seems therefore to favor the hypothesis that the blasts from Katmai did not owe their destructiveness to their chemical composition but to other causes. If this is correct it would fall into line with the best testimony as to the blasts from Pelee and Taal.

In the case of Taal, Worcester[5] believes that the principal reason for the destructiveness was the heavy charge of small

[5] National Geographic Mag. 23 : 350. 1912.



*Photograph by R. F. Griggs*

A CLUMP OF HAREBELLS IN A CREVICE IN KATMAI VALLEY.

Such crevice plants on exposed cliffs close up to the volcano indicate the absence of any great concentration of poisonous gases in the fumes.

particles of ejecta carried by the blasts, which gave them the effect of terrific sand blasts. This he inferred from the manner in which the bark and trunks of trees were shredded where exposed, and from the fact that even very thin fabrics sufficed to protect the flesh of victims which otherwise suffered severely.

There is, however, little evidence that a sand blast accompanied the eruption of Katmai. Near the volcano and in Soluka Creek, at a distance of about ten miles, the limbs of the trees and bushes were damaged by the *hail* of falling ejecta which must have been of considerable violence in areas where so much ash and pumice fell. But no evidence of shredding by sand blasts, such as Worcester figures, was seen.

The only place on the mainland where investigations were made to ascertain the manner of death of the vegetation within the first year after the eruption was at Russian Anchorage. (Griggs[2]). Here the *buds* of the alders had all been killed, but the bark was not only intact but alive and in condition to have made a complete and rapid recovery if there had been living buds to furnish an outlet for the vitality of the plants. (See page 184.) The present appearance of the trees in Katmai Valley indicates that the eruption probably left them in the same condition. (See page 185.) It is difficult to see how such damage could be accomplished by a sand blast. It would seem much more likely to have resulted from hot winds.

As would be expected, the zone of complete destruction by the blast is surrounded by an area of minor injury. This is the third of our series of zones which we passed over above without discussion. It has been observed, especially in the area between the mouth of Katmai River and Kashvik Bay. Because of the position of the mountain wall of Katmai Valley, the area of devastation does not intergrade with this district of slight injury but is sharply separated from it.

Since this district lies out of the area covered by wind blown ash, the ashfall here is almost devoid of dust and fine particles, being composed of fragments of pumice heavy enough to be relatively little affected by air currents. The total amount of ash (about one inch) was so slight as to do practically no damage in itself. And, at first sight, we were inclined to conclude that the vegetation in this area was in no way injured by the eruption, but closer examination indicates that the bare places on

the tops of a number of high knolls are probably results of the blast. There are a few groves of dead trees which, being exposed toward the volcano, likewise find their most reasonable explanation in the blast.

*Photograph by R. F. Griggs*

ALDERS ALMOST DESTROYED BY HAVING THEIR BUDS KILLED.

The cambium was everywhere alive and wherever a bud escaped it grew out with undiminished vigor. Russian Anchorage, July, 1913.

ZONE OF HEAVY ASHFALL.

We come now to the consideration of conditions in the fifth zone where the vegetation, in addition to being swept by the blasts already discussed under the preceding heading, was deeply buried under an ashfall so heavy as to prevent the restoration of an herbaceous ground cover. Concerning the conditions of death in this area but little needs to be added to what has already been said in the preceding section, for the working of the added agent of destruction is so simple as to require no particular exposition.

*Photograph by R. F. Griggs*

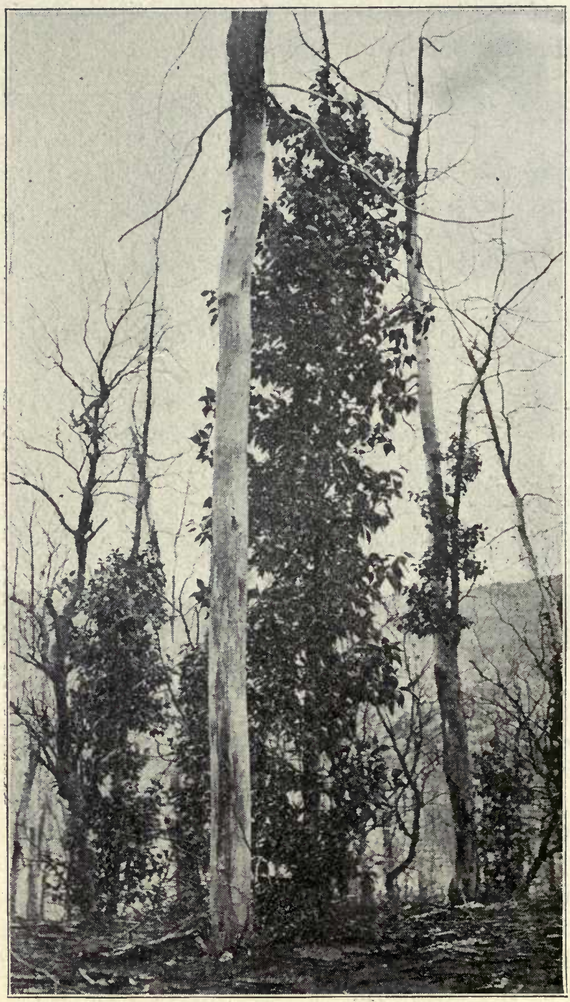
INJURED POPLARS IN LOWER KATMAI VALLEY.

The branches and ordinary buds were all destroyed. The new growth has come from dormant buds protected by a heavy growth of bark on the large branches.

Curiously enough the chief interest in this zone lies, not in the death of those plants which perished, but in the circumstances surrounding the survival of the few that persist. For these not only bear upon our original problem, that of revegetation, but also throw some interesting side lights on the character of the eruption.

Inasmuch as the area near the volcano was not visited until three years after the eruption, the observations concerning these survivals were perforce made on plants which had begun

to recover. The data are, therefore, somewhat complex, including, beside the effects of the eruption proper, secondary effects partly direct consequences of it and partly subsequent restorative reactions of the plants. It will be advisable, first, simply to describe the present condition of the vegetation, after which some attempt may be made to analyze the data with a view of ascertaining what occurred in the eruption and what reactions the plants have made since.



*Photograph by R. F. Griggs*

IN MANY CASES LARGE TREES PERISHED WHERE SMALL ONES SURVIVED.

See text page 199 for explanation.

### PRESENT CONDITION OF SURVIVING TREES.

Because of the difference in the habit of growth, the survivals among the various species of trees show quite different degrees of injury. Balsam poplars (*P. candicans*)* were the only large trees. All of the growing parts and all of the ordinary buds of these were killed; but some of the dormant buds, buried deep in the thick bark of the large branches, survived and have grown out forming short, bushy brushes, which give the trees a most outlandish appearance. (See page 185.)

In some places it may be seen that the smaller trees survived where the taller ones, standing beside them, perished. The taller trees were, of course, more exposed, and protected the smaller to a certain extent, but it is not obvious at first why their own lower branches, which were protected to the same extent as the adjacent saplings, have not survived. (See page 186.) Sometimes only a few buds on a very large tree have survived. The most extreme case of this sort of thing observed is shown on page 192. In other cases the bark is all dead except for a very narrow strand up one side of the tree which supplies the few new branches. (See page 198.)

The alder, (*A. sinuata*), which is the most characteristic Alaskan bush everywhere, was simply exterminated. Not until we had explored a considerable part of Katmai Valley did we find so much as a single live sprig of alder, and then we saw only two or three small shoots coming up from the roots.

The birch, (*B. kenaika*), the Alaskan representative of our paper birch, has suffered only less severely than the alder. Throughout the main valley it was destroyed, but in the more sheltered conditions of Soluka Valley new sprouts from the roots are fairly abundant.

The Alaska willow, (*Salix alaxensis*), suffered less than any other tree. In many places it has, in fact, almost completely recovered from the effects of the eruption. This is probably due to its capacity for forming adventitious roots on burial. (See below, pages 200–202). The other willows, *Salix nuttallii*, *Salix barclayi*, and *Salix bebbiana* have also recovered to a considerable extent, though their new growth is much less luxuriant than in *Salix alaxensis*. *Salix nuttallii* in particular shows an interesting reaction of tops as well as roots. (See page 201.)

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* The writer wishes to extend his thanks to Messrs. Paul C. Standley and A. S. Hitchcock of the National Herbarium, who kindly verified the determinations of the plants collected.

*Photograph by R. F. Griggs*

A DEVIL CLUB GROWING THROUGH THE ASH,

This plant has developed the "two storied" root system, characterisric of the buried vegetation. One set is just beneath the surface, another in the old soil. The three layers of the ashfall show well. Lower Katmai Valley—ashfall 20 inches.

### HERBAGE INJURED LESS THAN TREES.

Beneath the trees, the ground is for the most part absolutely bare. Wherever the ashfall amounted to three feet or more nothing could come through. Apparently there were no surface cracks as around Kodiak. At least no evidence of them remains, and the ash near the volcano was so much coarser grained than that deposited at a distance that "mud cracks" would hardly be expected. Consequently, conditions were much less favorable for the penetration of the ash by the buried herbage. But, although the herbage was almost completely smothered by the ashfall, there is good reason to believe that it suffered less from the eruption itself than did the trees. While the trees remained exposed to the elements throughout the period of the eruption, the herbs were quickly covered with a protecting blanket of ash which shielded them from further injury. Where this blanket was later removed by the agents of erosion, the smaller plants have come up in their former profusion and are fruiting freely.

This is true throughout Katmai Valley. And even on the slopes of the volcano itself, every area bared of ash is occupied by plants which survived the catastrophe. *Wherever the ash covering has been removed, the old herbage has sent up new shoots.* On "Prospect Point" for example, a high rocky hill 500 feet up the slopes of the volcano, a few living plants were found in 1916 including the following: *Potentilla villosa* (in flower), *Salix arctica*, *Salix glauca*, *Rhodiola rosea* (flowering), *Carex sp.* (flowering), *Oxyria dignyia* (flowering), *Cerastium sp.*, *Heuchera glabra*, *Dryopteris droypteris*, three species of grasses, *Polytrichum* and another small moss. The particular species are, however, of little importance for the list includes most of the plants which happened to occupy the denuded area before the eruption. With the living were the dead remains of only three others, viz., *Alnus sinuata*, *Diapensia lapponica* and *Silene acaulis*. On the lowland a few hundred yards farther from the crater were found: *Calamagrostis langsdorfii*, (fruiting), *Carex sp.* (fruiting), *Equisetum arvense*, *Rubus spectabilis*, *Sanguisorba sitchensis*, and *Artemesia tilesii* (flowering). It could be plainly seen that many of these plants were new shoots coming from old roots present before the eruption. At another place about ten miles from the crater, where an upland bog happened to be so located as to be cleared of ash, the following have reappeared:

*Athyrium cyclosorum, Trientalis arctica, Ledum decumbens, Betula rotundifolia, Empetrum nigrum, Vaccinium uliginosum* (fruiting freely), *Cornus suecica* (flowering), *Vitis-idæa vitis-idæa.* And so, if one should take a census of the resurrected plants in various habitats, he could probably find representatives of most of the species in the flora.

*Photograph by R. F. Griggs*

EVENLY BEDDED STRATA OF KATMAI ASH LYING AS THEY FELL ON TOP OF A SNOW DRIFT.

The character of the contact and the absence of ice indicate that the ash was not hot as it fell. The blanketing of the ash prevented melting for five years. On Observation Mountain, only seven miles from the crater (June, 1917).

### FALLING ASH RELATIVELY COOL.

The testimony of such plants shows that the explosion of Katmai differed markedly from many eruptions in the low temperature of the ejecta. In the case of Tarawera, for example, Pond and Smith[6] report that the ejecta retained a high temperature for a considerable time after they had fallen, and that the forest was consumed by fires, started presumably by the hot ash. If such conditions had accompanied the explosion of Katmai the evidence of them would be plain today. But nowhere is there any evidence of fire, neither charred wood nor indications that the buried trees and bushes were injured by the heat of ejecta coming from Katmai itself. On the contrary, wood of the buried bushes everywhere throughout this zone, even high up on the slopes of the volcano itself, is sound and well seasoned as though kiln dried.

The survival of the buried plants is even more significant evidence of the condition of the falling ash. Had the ejecta been hot as they fell, the deeper deposits would have cooled off very slowly and almost certainly would have cooked the plants beneath. The survival of plants under coverings up to 15 feet in depth would seem to demonstrate conclusively that the deposits could never have had a very high temperature.

Over large areas the ash fell on snowdrifts which, instead of being melted as they would have been by hot ejecta, were insulated by the thick mantle of ash and have persisted until the present time. The picture on page 190 shows a cavern caused by local melting of such a snowdrift which remained unchanged for five years after the eruption. The strata of ash lie as smoothly over the snow as over the bare ground, and there is not the least indication of irregularities due to superficial melting caused by the heat from the ejecta.

The low temperature of the ash is probably connected with the character of the ejecta, which are composed of exceptionally small fragments. There were no bombs of solid lava nor even large pieces of pumice thrown out from Katmai itself. All the ejecta are the type of frothy pumice and the largest lumps seldom reach ten inches in diameter. The finely fragmental character of the ejecta would operate in two ways to reduce the

[6] Pond and Smith. On the Eruption of Mt. Tarawera. Trans. New Zealand Institute, 19 : 362, 1886.

temperature which probably was very high before the explosion. First, smaller particles would be cooled more rapidly in their journey through the air. This would be much more important at a distance than on the slopes of the volcano. Second, the expansion incident to the conversion of the magma into frothy pumice would absorb much heat and reduce the temperature. This is probably the more important factor near the vent.

*Photograph by R. F. Griggs*

A TALL POPLAR ON WHICH ONLY A FEW BUDS SURVIVED.
It seems incredible that so slight a leaf surface should have sufficed to keep the extensive trunk and roots alive for four years (July, 1916).

### ALL SPECIES SUFFERED ALIKE.

All subsequent observation confirms and strengthens the point made in the former report, (Griggs[2]), of the remarkable absence of specific effects of the eruption proper on different plants. So far as can be seen, most of the flowering plants suffered alike. Where any perished, most perished, and where any escaped, almost all escaped.

The marked differences shown in the recoveries of different species are traceable in almost every instance to some readily observable difference in habit or adaptation. Thus *Equisetum arvense* came through where nothing else could, not because of any greater toughness of constitution or greater capacity to endure burial, but because it could send out runners of a greater length than other plants. *Salix alaxensis* recovered better than the poplars, not because more hardy, but because of its capacity of forming adventitious roots which the poplars lacked. Where here and there a few plants survived in the region of total destruction, it was for the most part due not to superior resistance but to a fortunate location.

This point is well brought out by a comparison of the condition of certain of the surviving plants in Soluka Valley, where the ashfall was six feet, accompanied by a blast, and around Kodiak, where the ashfall was one foot without marked elevation in temperature. All of the species mentioned were common in both localities before the eruption.

| SOLUKA VALLEY. | KODIAK. |
|---|---|
| *Alnus sinuata* (only one seen alive) | Not injured. |
| *Equisetum arvense* (scarce) | The most abundant survival. |
| *Athyrium cyclosorum* (thrifty) | No survivors observed. |
| *Trientalis arctica* (flowering) | No survivors observed. |
| *Ledum decumbens* (flowering) | No survivors observed. |
| *Betula rotundifolia* (thrifty) | Only occasional. |
| *Empetrum nigrum* (thrifty) | Very rarely survived, was ubiquitous. |
| *Vaccinium uliginosum* (fruiting) | No survivors observed. |
| *Sanguisorba sitchensis* (flowering freely) | Abundant. |
| *Cornus suecica* (thrifty) | Rarely survived. |
| *Vitis-idæa vitis-idæa* (thrifty) | Rarely survived. |

Most of these plants were found on Soluka Creek in the upland bog from which the ash was cleared away, as mentioned above. The reason for the survival of these plants here, when they were practically exterminated around Kodiak, clearly lies not in any peculiarity of the species themselves, but in the accident of a favorable situation.

*Photograph by D. B. Church*

PATCHES OF RESURRECTED HERBAGE IN CLEARED AREAS.

Contrast the bare ground still covered with ash round about. The roots from which these plants grew up were buried for three years until the ash was swept away by the Great Flood of July, 1915.

*Photograph by R. F. Griggs*

DETAIL FROM THE PATCH OF RESURRECTED HERBAGE SHOWN ABOVE.

The high water mark of the flood, which washed off the ash after it had buried the plants for three years, is plainly shown by the line on the bank and on the trees. The vegetation comprises a considerable number of species, see text page 196.

### PLANTS WHICH LAY DORMANT FOR THREE YEARS.

At first it was supposed that such recoveries of buried herbage could occur only when it was exhumed soon after the eruption, for it did not seem possible that plants could survive burial for many months. But the observations of 1916 showed that this supposition was incorrect, for it was found that in many places where the ash had lain undisturbed for three years, until removed by the great flood of July 1915, plants from the old roots had come up in all their original vigor, forming in some places a rank and thrifty growth. (See pictures opposite). When first observed, an effort was made to interpret these patches in some other way than as survivals of such prolonged burial. It was first thought that the areas must have been uncovered at an earlier date, for it appeared incredible that they could have withstood a burial of three years. But some of the areas were so associated with high water marks many feet above the valley, that could only have been made by the great flood, the date of which was known, that the duration of the period of burial became a certainty. It was then thought that the rich soil exposed by the flood might have served simply as a favorable substratum on which wind distributed seeds had started, while they failed on the adjacent banks of ash. But this hypothesis was rendered untenable when it was observed that this new growth appeared only in places where the *original* surface of the ground had been left undisturbed by the flood waters. Wherever the wash had been stronger, so as to carry off not only the ash layer but also the surface soil with its included seeds and remnants of vegetation, the bared areas, although as rich as the surface soil, remained for the time, practically barren.

The condition of the plants themselves was more positive evidence, however, for it admitted of only one interpretation. The new growth could be traced in most cases directly back to the old stocks grown before the eruption. Associated with these were, in many instances, the much weathered remains of the growth before the eruption, but no remains of growth of intervening years, such as would undoubtedly have been present had any shoots appeared in those years, were noticed. No plants were found which showed any indication of growth for several years back.

Finally, crucial proof of the ability of the underground parts of plants to retain their vitality when buried was furnished at Kodiak when I found an old rhizome of Equisetum, which I had exposed in excavation in 1915, that had put forth new shoots the following year, as detailed in the first paper of this series, this journal page 32.

The plants which had thus recovered after having lain dormant for three years beneath the ash covering were some of the most characteristic species of the region, including: *Calamagrostis langsdorfii* (fruiting), *Equisetum arvense, Carex sp.* (fruiting), *Rubus spectabilis, Salix sp., Rhodiola rosea, Sanguisorba sitchensis, Artemesia tilesii, Poa sp., Streptopus amplexifolius, Cardamine umbellata, Cerastium sp.*, and *Juncus sp.* With the root survivals were also numerous seedlings, sprung from seeds that had lain dormant under the ash. *Carex* and *Sambucus pubens* were abundant in all stations. *Polemonium acutiflorum* (from seed ?), *Geranium erianthum*, and *Heuchera glabra* were also found but less commonly.

## CAUSE OF DORMANCY.

There is little reason for supposing that the species found as root survivals have any special ability to endure burial, or that others in the same areas had succumbed, leaving only the most resistent to survive. The areas in question were not large. If larger areas with more varied habitats had been exposed, the list of survivals would probably have been considerably increased. The fact that this ability to recover after such a period of enforced dormancy was shown by various species of plants, directs inquiry to the physical conditions of the environment which made survival possible. Unfortunately not enough is known of the environmental conditions to enable one to make any satisfactory hypothesis as to the causal factors, but some facts bearing on the situation may be enumerated. The first supposition would naturally be that a low soil temperature was the responsible factor. But the facts of the situation will hardly permit one to assign to it the principal role in this connection. It must be remembered that the Katmai district is south of the region where the soil is permanently frozen.

The August soil temperatures at a depth of 30 inches were found to vary from 38°–56° F. in different situations. The

most common readings were about 43° F. as compared with air temperatures averaging about 50° F. Thus the temperature beneath the heavy ash blankets on the mainland may be presumed to be in the neighborhood of 40°. F, But the Equisetum at Kodiak, which revived on being dug up, had been buried only a few inches beneath the surface and must have been at a temperature well above the growth minimum for several months in each of the three years of its burial. Next to the low temperature, one thinks of desiccation as a means of maintaining a dormant condition in plants. But desiccation cannot have been a factor in this case for the country is notoriously wet. Indeed, the Equisetum had lain below the water table in all but the driest months of the year. One might go on and consider the possible lack of oxygen and other factors, but there was nothing in the field to suggest the action of such factors and no means available of estimating their probable effect.

There is some evidence that a similar dormant period may follow the shock of an eruption even in a tropical country, where the vegetation is not accustomed to such seasonal variations as the plants of the Katmai District are subjected to by the long winters. In the revegetation of Taal, which has been studied in more detail than that of any other volcano up to the present, Gates[7] found in October, 1913, nearly three years after the eruption, only three clumps of bananas and none of bamboo. But, "in April, 1914, bananas were fairly abundant and indicated quite well the positions of many of the former houses," while bamboo was also prominent. Brown, Merrill and Yates[8] furthermore submit evidence which indicates that a large proportion of the new vegetation of Taal may have come from old roots which lay dormant for a long period.

### RESTORATIVE REACTIONS OF SURVIVING PLANTS.

From what has been said above, it is evident that those trees, which were not killed outright by the eruption, were so injured that the chances of their ultimate recovery must have appeared remote if they had been examined soon after the

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[7] Gates, F. C. The Pioneer Vegetation of Taal Volcano. Philip. Journ. Sci. Ser. C, 9: 391-434. Pls. 3-10. 1914.

[8] Brown, Merrill and Yates. The Revegetation of Volcano Island, Luzon, Philippine Islands Since the Eruption of Taal Volcano in 1911. Philip. Journ. Sci. Ser. C, 12 : 177-248. Pls. 4-16. 1917.

*Photograph by D. B. Church*

A POPLAR IN WHICH A FEW TWIGS ARE KEPT ALIVE BY A NARROW STRAND OF BARK (concealed in picture).

All the rest of the bark has died of starvation and dropped off.

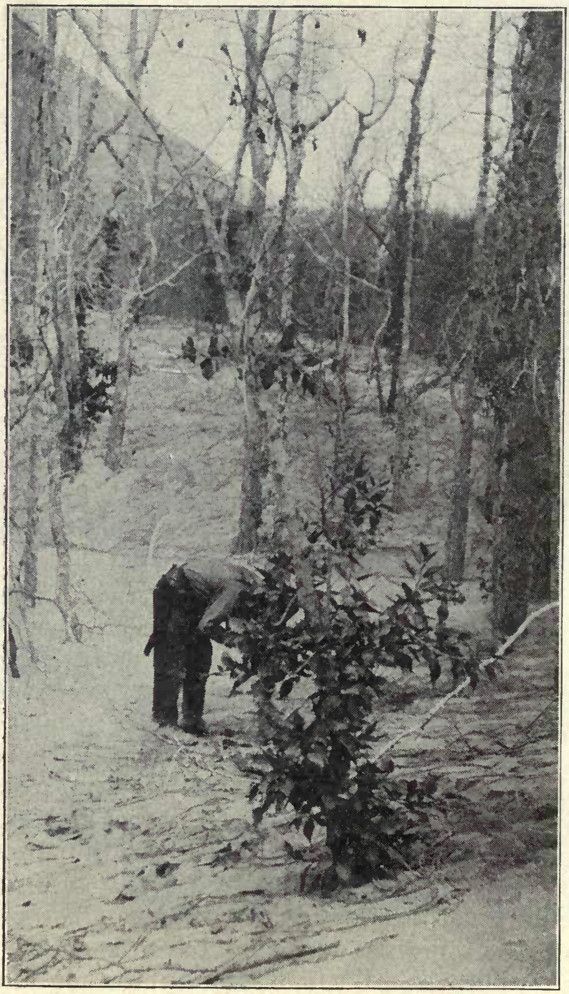
eruption. The problem which had to be met by these trees was to maintain the extensive system of uninjured roots and branches with almost no leaves until new growth could provide the leaf surface necessary to feed the rest of the plant. The capacity shown by some of the trees of adjusting themselves to such abnormal conditions is remarkable. The most extreme case was found on Soluka Creek where a tall poplar was dead except for a very few twigs in the top. (See page 192.) The bark of this tree, which was 41 inches in girth, was dead along two strips 6 and 4 inches wide, leaving two bands of living bark 15 and 16 inches wide and 40 to 50 feet high to be supported by only the handful of leaves at the top. In another case all the bark had dropped off except the narrow strip connecting with the new growth, (see page 198), leaving the tree apparently stripped when viewed from the other side. Since the side of the trees where the bark persisted bore no relation to the position of the volcano, there is no reason for believing that the rest of the bark was killed in the eruption, this only escaping. It is rather to be supposed that the remainder of the bark died of starvation for lack of ability to put forth leaves.

### TREES STARVING FOR LACK OF LEAVES.

Along with instances such as the foregoing, where trees have managed to survive with very small leaf areas, are others where they have succumbed through inability to tide over the period intervening before an adequate number of leaves could be grown. On many of the poplars the new twigs, after growing for a little while, blighted and died. On such trees it could be seen that the twigs farthest from the roots were dying first, and many cases were seen where the new twigs close to the ground were continuing to thrive where those higher up had long since withered away. (See page 200). But in others, the whole tree had perished after a futile attempt at renewed growth. This blighting is interpreted as due to the breaking down of the conducting or root systems, which was in turn caused by malnutrition from the lack of leaves. In this is found the explanation of the survival of saplings where large trees perished, as noted above. The new leaves were able to keep the roots and bark of the sapling alive, but not sufficient to maintain the more extensive roots and tops of the large trees. Thus many trees, comparatively but little injured in the eruption itself, have died subsequently because of inability to make good the destroyed buds.

### NEW ROOTS AT THE SURFACE OF THE ASH.

Those plants like the willows, which readily put out new roots, were at a considerable advantage in recovering from the eruption, as compared with those without this power, like the poplars. For such plants, by putting out new shoots at the surface of the ash and new roots just beneath, could start afresh on the same basis as young plants without the necessity



*Photograph by R. F. Griggs*

A POPLAR WHOSE NEW SHOOTS ARE BLIGHTING, BEGINNING AT THE TOP, BECAUSE OF STARVATION OF THE ROOT SYSTEM.

of carrying the over-extended tops and roots of the old trees. This is very conspicuous in many places where the Alaska willow (*Salix alaxensis*) grew among the poplars. In the course of three years the willow practically made good its losses and was as thrifty as ever, while the poplars were more dead than alive.

In places where the ash, after lying on the ground for some time, has been washed away by streams, exposing the buried parts of such trees, the difference between the willows and poplars is very striking. The dead poplar trunks stand as they were at the time of the eruption, but the willows have grown extensive systems of new roots. These are not distributed throughout the length of the buried stem but are almost confined to the region immediately beneath the former surface of the ash. (See page 202.) The advantage of the willow over the poplar is obvious. That these new roots were really the decisive factors in the survival of the willows is shown by numerous cases where trees which had survived burial had succumbed to the removal of the ash layer, with the consequent dislocation of the new roots.

This type of root reaction was not confined to the willows but was found in a number of other plants as well. In general it may be stated that the stems of buried plants either remained unchanged, or reacted in this manner, developing the characteristic two-storied root system. The plants in which this reaction was found were: *Salix alaxensis*, *Salix nuttallii*, *Salix glauca*, *Echinopanax horridum* (see page 188), *Calamagrostis langsdorfii*, *Betula rotundifolia* (feeble), *Rubus spectabilis*, *Vaccinium ovalifolium*, *Deschampsia cæspitosa*.

STEM REACTIONS.

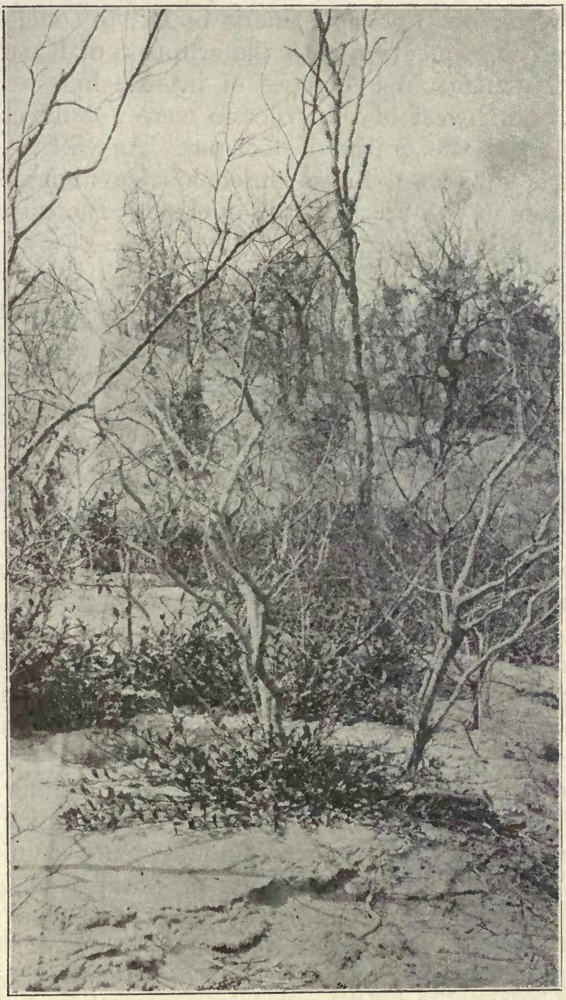
The reactions of the aerial parts of plants remain to be considered. For the most part the new growth gives no indication that unusual conditions were introduced in burial beyond those incident to the merely mechanical action of the ash. But a few species show interesting reactions to burial. The most conspicuous case is the pussy willow (*Salix nuttallii*). Before the eruption this grew as an erect bush two or three meters tall. In many cases all parts above the ground were killed in the eruption, but new shoots have been put out from the surface of the ash. These show no tendency to form new branches like the original trunk, but spread out flat on the

*Photograph by D. B. Church*

THE NEW ROOT SYSTEM OF A WILLOW EXPOSED BY A SHIFT IN FICKLE CREEK.

To the left may be seen the surface of the ash, while the stream at the right has cut into the original soil. The new roots came out eight feet above the original root system. Note the absence of such roots on the poplars in the bank and the comparative insignificance of their new growth.

ground, forming a rosette or mat. (See below.) An investigation of the physiological causes by which this reaction is brought about would yield exceedingly interesting results if one could find the means of attacking the problem. A satisfactory solution should throw much light on the causes underlying the development of prostrate shrubs in general, such as the prostrate juniper of the north and the prostrate yew of our own woods, both forms being closely related to erect growing species.



*Photograph by R. F. Griggs*

Before the eruption *Salix nuttallii* grew as an upright tree. The tops were killed and the new growth forms prostrate mats on the surface of the ground.

## ZONE OF INCINERATION.

We come now to the consideration of the final zone. Curiously enough, areas of complete sterilization in which all vestiges of life were consumed by fire occur only at one side of the volcano, being confined to the vicinity of the Valley of Ten Thousand Smokes. On the other side of the range in Katmai Valley there is, as already remarked, not the slightest evidence of fire in connection with the eruption. Since the ashfall is much greater on that side, one is bound to conclude that no fires occured in connection with the eruption of Katmai proper, but that the manifold evidences of intense heat to be found in the area northwest of the volcano were not due to agencies emanating from the crater of Katmai. As will be seen, this conclusion is supported by so much local evidence of a positive character in the area burned over that there can be little question of its correctness.

Throughout the upper portion of the Valley of Ten Thousand Smokes and its branches not a vestige of the vegetation which must once have covered it is to be found. So complete has been the destruction that no evidence of what happened to the plants remains to tell the tale. As we explored this district we were for a long time altogether at a loss to understand what had happened. We could not reasonably suppose that the area had been devoid of all vegetation before the eruption. Indeed, we knew that there were once good sized trees far up toward Katmai Pass. On the other hand, in the light of our acquaintance with conditions on the opposite side of the range, we were hesitant in hypothecating destructive agencies so intense as to eradicate the very evidence of their action. Nevertheless we could see plainly that over a considerable part of the area the gray-green sandstones had been burned to a brick red by the heat of the eruption.

It was not until we extended our explorations down toward the foot of the great mud flow that fills the valleys throughout this zone that we began to find evidence confirming the suspicions aroused by the absence of plant remains around its head. In its upper portion the mud flow is so thick that we could nowhere find a stream-trench or fault line sufficiently deep to expose the relations of the mud flow to the underlying original soil. But at its lower end, where it is

thinner, there is abundant opportunity to observe its effect on vegetation.

Here the mud flowed down through the forest engulfing the trees that stood in its path. (See below). If one walks along the edge of the flow where its effect on the trees can best be observed he can see what happened in the clearest possible fashion. The trees and bushes everywhere show evidence of disturbance by the moving stream of mud, but there is no indication of such violent action as would have been left in the wake of a torrent of water, for none of the trees

*Photograph by R. F. Griggs*

BURNED REMNANTS OF THE TREES ALONG THE EDGE OF THE MUD FLOW.

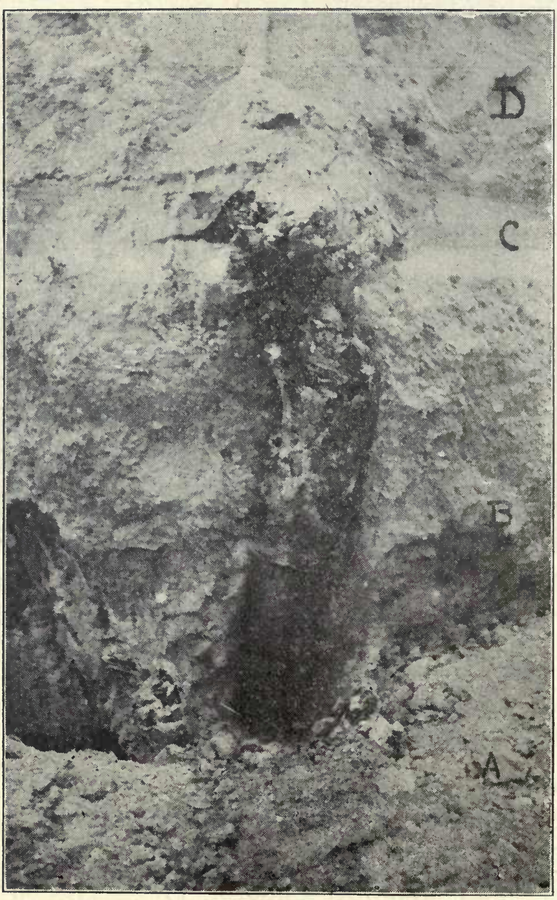
The trees on higher ground at the right, out of reach of the mud, though killed by the eruption, show no sign of fire. The mud flow, which so incinerated vegetation, was entirely independent of the explosion of Katmai. (See No. III of this series of articles).

are uprooted or broken up by the flow. In many places the tops protrude above the surface of the solidified mud. Such old tops are, however, but loosely held by the mud. If one takes hold of them they pull right out, when it is found that they are charred through about a foot below the surface.

The stream canyons in this district show abundant sections of the mud containing such trees. The charring action was so thorough that every particle of vegetation touched by the mud

is completely reduced to charcoal. Some of the logs so charred are as much as a foot in diameter. (See below). In other places where the original ground has been uncovered by erosion, the remains of the mat of vegetation that covered it lie in place as a sheet of charcoal. (See page 207).

At a few places around this lower end of the mud flow the trunks of the trees standing above the level of the flow are scorched as though by a grass fire. But, for the most part,




*Photograph by L. G. Folsom*

THE TRUNK OF A TREE ENGULFED BY THE MUD FLOW.
Although a foot in diameter, it was entirely reduced to charcoal by the heat of the mud flow. This section was found at the extreme limit of the zone of incineration, seventeen miles from the crater of Katmai.

no evidence remains to indicate the cause of the death of this forest. Its general aspect is much like that of the forests whose destruction has been attributed to blasts from the volcano, but differs in that here projecting shoulders of the mountains, etc., seem to have given little if any protection to the trees behind them.

Halfway up the Valley, however, we found a mountain-side which had every appearance of having been swept by a fire that had blackened the surface of all the remains of the vegetation, which had consisted of herbs and dwarf shrubs.

*Photograph by R. F. Griggs*

MAT OF VEGETATION REDUCED TO CHARCOAL BENEATH THE MUD FLOW.

The original surface of the soil has been uncovered by erosion.

This was the last sign of plant life found in the Valley, for further up the rocky hills were all absolutely devoid of plant remains. Unless they were originally totally barren, which seems impossible, they must have been so thoroughly burned over that all plant remains were consumed. While it may be somewhat uncertain how large an area was so completely sterilized as this, there can be little doubt but that such was the fate of all the district whose rocks were baked red by the heat.

One cannot consider these evidences of consuming heat without speculating as to the exact conditions under which it worked;

what the temperatures may have been; what chemicals may have been associated with its action; whether deadly fumes were given off along with the high temperatures; why charring was for the most part subterranean; why the destructive agencies were apparently more intense toward the head of the Valley; and a number of other similar problems. But these questions more properly belong to the geological discussion of the events of the eruption. They will, therefore, be passed over here and left for later discussion in their proper place.

The area included in this ultimate zone of complete annihilation is that of the basins in which fissure eruptions have occurred, namely, all of the valleys now occupied by volcanic vents and the upper part of Mageik Valley down to Observation Mountain, which is occupied by a mud flow similar to that of the Valley of Ten Thousand Smokes, and gives clear evidence of having been formerly the seat of fumarole action. Altogether this area of annihilation covers some 100 square miles.

Before concluding, it may be desirable to add a few statements concerning animal life, for in the zones of greater destruction the whole story may be told in a few sentences. In the last zone, all animal life was of course annihilated. In the district of deep deposits all animals were destroyed except for a few wood boring insects, which not only were protected by their habitats, but were furnished with an abundant supply of food in the trees killed by the eruption. Within the area of destructive blasts (Zone 4) the same condition prevails, but here one finds an increasing number of survivals favored by some special circumstance of habitat or situation.

## SUMMARY.

The effect on the observer of a study of this stupendous eruption, as revealed by its effects on vegetation, is like that of any other consideration of its phenomena and serves greatly to augment his conception of its surpassing magnitude. Passing our results briefly in review will aid in giving a single concrete picture of this tremendous cataclysm, susceptible of comparison with other great eruptions.

1. Rains bearing sulphuric acid in such concentration as to destroy gardens occurred as much as 300 miles from the volcano.

2. An area of 7,300 square miles was covered with ash so deeply as to destroy the smaller plants.

3. Death-dealing blasts from the volcano killed trees 25 miles away, destroying the forest over an area of more than 1,500 square miles.

4. Ashfall, so heavy as to obliterate all herbaceous plants except on steep hillsides, etc., covered an area of about 970 square miles.

5. Mud flows so hot as to reduce to charcoal all vegetation with which they came into contact were poured out over an area of about 53 square miles.

6. An area of about 39 square miles, in which there is no trace of former vegetation, was probably swept by fires of great intensity, making the total area in which all life was annihilated 100 square miles.

# V. THE NITROGEN CONTENT OF VOLCANIC ASH IN THE KATMAI ERUPTION OF 1912.

J. W. Shipley,
Chemist of the 1917 Expedition.

The opportunity to study the revegetation of a large area buried by volcanic ash comes but rarely. When in June, 1912, following several explosive eruptions, Mt. Katmai ejected from its crater about five cubic miles of ash and pumice and distributed it over the adjacent region to a depth of fifteen feet, gradually diminishing until at Kodiak, 100 miles to the eastward, it covered the island with a layer of fine ash ten inches deep, such an opportunity was presented on a scale unequalled by any volcanic eruption since the dawn of interest in such matters. All vegetation near the volcano was smothered and killed, leaving large areas covered with a finely divided soil which, while perhaps containing the mineral requisites necessary for plant growth, was absolutely free from organic matter and micro-organisms. An abundant rainfall, and climatic conditions favoring the growth of a diversified flora, made this region a fertile field of observation. Flanked on the south and west by the abundant pre-eruptive flora, while here and there throughout the destroyed area oases of plants are preserved, this barren area will become, in time, again clothed with vegetation.

The several expeditions of the National Geographic Society, sent out under the direction of Dr. R. F. Griggs, had as their primary object the observation of the revegetation of this remarkable region. It soon became apparent that one of the principal controlling factors, in the revegetation problem, was the supply of nitrogen as a necessary constituent of plant growth. Consequently the 1917 expedition was equipped with the necessary materials and apparatus for making field determinations of the ammonia and nitrite nitrogen content of the ash, and for collecting samples with a view to further analysis in the laboratory. This work was placed in charge of the author.

The nitrogen supply for plants attempting to gain a hold upon this otherwise fertile soil was made the subject of special study. Not only were observations made upon the water soluble ammonia and nitrite content of the ash, but determinations of the total nitrogen content of the volcanic detritus were made in the laboratory upon all representative samples. Determinations were also carried out upon the pre-eruptive soil so far as the tundra may be considered as representing it, and in addition a series of observations was made upon the nitrogen content of the rainfall and upon the water derived from melting snow.

*Photogragh by D. B. Church*

A CHEMICAL LABORATORY IN THE KATMAI REGION.

Only a chemist can understand the difficulties of making quanitative analyses where one must carry his laboratory on his back.

Ammonia nitrogen was determined by color comparison with a standard ammonium chloride solution, using Nessler's reagent in 50 cubic centimeter Nessler tubes about 25 centimeters high. Nitrous nitrogen was determined by comparison with a standard solution of sodium nitrite, using Griess's reagent in the above mentioned Nessler tubes. These reagents were prepared according to the directions outlined in the

A. P. H. A. Standard Methods of Water Analysis, and were carried to the field in small reagent bottles provided with a special device to guard against leakage or contamination. No attempt was made to use a set of standard colors, but each determination was matched against standard solutions. On returning to the laboratory the reagents and standard solutions used on the expedition were checked up, and, in the case of the nitrous nitrogen, a suitable correction for deterioration in the standard solution of sodium nitrite was applied to the observations. A copper still was carried into the field, but fortunately the use of distilled water was obviated by the almost complete absence of ammonia and nitrous nitrogen in the surface and spring waters of the Katmai district. Moreover, the water from melting snow was found to be almost free from these nitrogen compounds. (For a detailed statement of these matters, see the following paper of this series, pages 230–234).

The samples of ash investigated were air dried on aluminum plates, and 100 grams weighed on a small hand balance. This amount of ash was then placed upon a previously well washed filter paper in a five inch glass funnel, and leached with successive portions of ammonia and nitrite free water until approximately 150 cubic centimeters of filtrate were obtained. This filtrate was then made up to 150 cubic centimeters and 50 cubic centimeter portions used for comparison with the standard solutions. A check on the results was always kept by testing for ammonia 50 cubic centimeters of the last washings of the filter paper previous to adding the ash. It was really surprising how persistently traces of ammonia clung to the filter papers. Moreover the ubiquitous ammonium compounds were constantly being met with in the most unexpected quarters, and the greatest care had to be exercised in preventing contamination of the samples collected for analysis. On one occasion several samples of dry ash were carried to camp in ordinary brown paper bags that had not previously been used in any way. Irregularities in the analyses of the ash taken from these bags led to the suspicion that even the dry ash had been contaminated by contact with them. A water infusion of the paper bags, when treated with Nessler's solution, gave a heavy yellow precipitate of the ammonia complex. Ever afterwards all samples were collected and carried in glass or metal containers previously well freed from ammonium compounds by efficient washing.

Table I contains the results of the analysis of a seven-foot deposit of the volcanic ash in position. A mountain stream, undermining the deposit, exposed the horizontal layers as a cut bank, and this bank was cut into with a spade for over three feet and samples taken from the exposed vertical section. The analyses are the average of several closely agreeing results, excepting for the determination of total nitrogen. No. 6 is the average of two determinations.

The total nitrogen was determined in the laboratory on ten gram samples of the air dried ash by a modification of the Kjeldahl process. The diluted contents of the digestion flasks were made alkaline by ammonia free sodium hydrate solution

TABLE I.

NITROGEN CONTENT OF KATMAI ASH FROM A DEPOSIT, SEVEN FEET DEEP, ON OBSERVATION MOUNTAIN, ABOUT EIGHT MILES SOUTH OF KATMAI CRATER.

| | Parts Nitrogen per 100,000 | | |
|---|---|---|---|
| | $NH_3$ | $NO_2$ | Total N. |
| (1) Wind drifted layer, 4″ deep | none | none | ..... |
| (2) Top dust layer, 2″ deep | none | none | ..... |
| (3) Yellow layer, 10″ deep | 0.001 | none | ..... |
| (4) Gray layer, 32″ deep | 0.001 | none | ..... |
| (5) Terra cotta layer, 16″ deep | 0.001 | none | ..... |
| (6) Lower gray layer, 18″ deep | 0.002 | none | ..... |
| Mixed sample of all the above | ..... | ..... | 0.005 |

and made up to 200 cubic centimeters. Fifty cubic centimeter portions were then compared in Nessler tubes with standard ammonium chloride. Blanks, treated exactly as the ash samples, were run concurrently, and the ammonia content of the blank subtracted from that of the ash.

The lower layers of the ash deposit contained large pieces of pumice. These were discarded and the analysis made on the finer material. The relatively large ammonia content of the lower 18-inch layer may be attributed to contact with the pre-eruptive surface on which it rests. The upper layers have lost, presumably to the atmosphere, what little ammonia they may have possessed. It may be that all of the ammonia found in the ash has percolated upwards from the pre-eruptive soil, but the quantity is so small that it might equally well be considered to have come in rainwater. The eruption was accompanied by very heavy downpours, which would wash down not

only the normal amount of nitrogenous products in the air, but also any gaseous nitrogen products of the eruption. The small total nitrogen content of the ash precludes any possibility of the vegetation securing its nitrogen supply by any conceivable decomposition of the volcanic detritus. The material deposited by the Katmai Crater came from the igneous complex, and probably does not contain any of the sedimentaries of the region through which the volcanics extrude. Sandstones of this period, according to Stewart and Peterson[1], contain as

TABLE II.

NITROGEN CONTENT OF ASH FROM VARIOUS LOCATIONS.

| | PARTS NITROGEN PER 100,000 | | |
|---|---|---|---|
| | $NH_3$ | $NO_2$ | Total N. |
| (1) Wind blown ash, water saturated, on top of snow bank | none | none | ..... |
| (2) Wind blown ash, behind Camp IV, Observation Mountain | none | none | ..... |
| (3) Caked top layer ash on Observation Mountain, north of Camp IV | 0.004 | none | ..... |
| (4) Moist ash, similar to (3) | 0.004 | 0.0004 | ..... |
| (5) Ash one foot beneath (4) | none | none | ..... |
| (6) Sample similar to (3) | none | none | ..... |
| (7) Sample similar to (3) | none | none | ..... |
| (8) Ash along spring stream in which algae were growing, Observation Mountain | 0.002 | 0.00004 | ..... |
| (9) Ash four inches beneath (8) | 0.004 | ..... | ..... |
| (10) Ash, Katmai Mud Flow, Katmai Volcano | none | none | none |
| (11) Top layer ash, Katmai Volcano | trace | 0.00004 | 0.80 |

high as 65.5 parts per million of nitric nitrogen alone. The total nitrogen content of the Katmai volcanic ash is but 0.05 parts per million.

Table II contains observations made on surface samples of ash taken from the immediate neighborhood of the Volcano. Little or no ammonia and nitrous nitrogen were found. Algæ were observed growing in the ash at the base of Observation Mountain where a small spring arose. Determinations (8) and (9) relate to this ash. The complete absence of nitrogen from the sample of the Katmai Mud Flow is comparable to that of the volcanic ash included in Table I, for the Katmai Mud Flow is

[1]Stewart, Robt. and Peterson, Wm. The Nitric Nitrogen Content in the Country Rock. Utah Agriculture College Experiment Station, Bull. 134. June, 1914.

most probably a composite sample of the ashfall, formed by the slumping of large masses down the slopes of Katmai immediately following the eruption. The analyses listed in Table II were made upon representative samples of the surface ash contaminated very little, if at all, from the pre-eruptive soil. There may have been some admixture however, for the strong winds of this region drift the ash for long distances, and have laid bare the old soil on the exposed ridges and hills. The relatively high total nitrogen content of (11) might well be due to wind borne humus from the old soil, that found lodgment for the time being upon the moist top layer of the finely divided Katmai ash.

TABLE III.

Nitrogen Content of Some Miscellaneous Samples of Ash.

| | | Parts Nitrogen per 100,000 | | |
|---|---|---|---|---|
| | | $NH_3$ | $NO_2$ | Total N. |
| 1917. Aug. 15. | (1) Katmai River wash, seedling grass growing; cf. (5), pp. 226 and 229.... | 0.04 | 0.0004 | 3.20 |
| | (2) Same, and close to (1), but seedlings died; cf. (6), pp. 226 and 229........ | trace | trace | 3.20 |
| Sept. 15. | (3) Kodiak Island, Pillar Mountain, Vegetation Station No. 14; cf. (4), pp. 226 and 229........................ | 0.012 | trace | 0.80 |
| 1916. | (4) Sample 33, Katmai Church, stream borne; cf. (1), pp. 226 and 229...... | ..... | ..... | 6.40 |

The analyses included in Table III were made for the purpose of ascertaining whether the nitrogenous plant food in the ash was the determining factor controlling vegetation. The results must be interpreted in conjunction with the ferrous iron and free acid content of the same samples included in another paper[2], although the nitrogen content of (1) and (2) is very small and any difference appears to be in favor of (1), yet in the light of the ferrous iron content the difference in vegetative growth must be attributed to the well known toxic effects of this compound. The ash designated by (3) in the table was a wind blown drift on the flank of Pillar Mountain, Kodiak Island, on which, after five years, little or no vegetation had returned. Free sulphuric acid and ferrous sulphate were found in this sample also, but not to the same injurious extent

[2]Shipley, J. W. Scientific Results of the Katmai Expeditions. VI. The Water Soluble Salt Content, the Ferrous Iron Content and the Acidity of Katmai Volcanic Ash. Ohio Journal of Science, 19: 224-229, 1919.

as in (1) and (4). Sample 33, collected by Dr. Griggs in 1916, was found to contain twice as much total nitrogen as (1), in which seedling grass was growing, but the acidity and ferrous sulphate content was so high as to preclude the possibility of plants surviving.

Martin Creek, the principal affluent of Katmai River, flows in from the west and brings the drainage waters from

TABLE IV.

NITROGEN CONTENT OF RIVER DEPOSITED PUMICE AND ASH, KATMAI RIVER, MARTIN CREEK CAMP.

| 1917 | | Parts Nitrogen per 100,000 NH₃ | NO₂ | Total N. |
|---|---|---|---|---|
| July 1. | (1) River deposited ash, *Lupinus nootkatensis* in blossom | 0.02 | 0.00018 | ..... |
| July 2. | (2) River deposited ash, *Lupinus nootkatensis* in blossom | 0.032 | 0.00018 | ..... |
| July 2. | (3) River deposited ash, three foot radius from (1) | 0.024 | 0.00016 | ..... |
| July 2. | (4) River deposited ash, three foot radius from (2) | 0.026 | 0.0002 | 0.88 |
| July 2. | (5) Mixed sample from around several lupine roots | 0.02 | 0.00026 | ..... |
| July 2. | (6) Mixed sample from around several lupine roots | none | 0.0002 | ..... |
| July 2. | (7) Sample of ash, etc., two feet beneath (1) | 0.028 | 0.0001 | ..... |
| July 2. | (8) Brown humus soil, lupines growing | 0.02 | none | ..... |
| Aug. 15. | (9) Ash among roots of lupines, near spring north of Martin Creek | 0.006 | 0.00006 | ..... |
| Aug. 15. | (10) Ash among roots of lupines growing farthest out on ash deposited by Katmai River | 0.006 | 0.00004 | 0.50 |
| Aug. 15. | (11) Ash around roots of ripened lupines | 0.002 | 0.00006 | ..... |
| Aug. 16. | (12) Martin Creek, black sand, lupines growing | trace | none | ..... |
| Aug. 16. | (13) Ash bed of creek below spring, near trail, sickly grass seedlings | 0.004 | 0.00004 | ..... |
| Aug. 16. | (14) Old soil surface, many plants growing. | 0.004 | 0.00008 | ..... |

the southerly slopes of Mt. Martin and Mt. Mageik. This area was to the windward of the Volcano at the time of the eruption and consequently received but a slight fall of ash and pumice. The pre-eruptive vegetation along its head-waters still persists, and the frequent floods coming down throughout the summer might be expected to scatter this vegetation far and wide over the everchanging ash and pumice bars of the lower Katmai Valley. Just below the junction of Martin Creek with Katmai River lies an extensive flat covered by river

borne wash of ash, pumice, and black sand. The latter comes from the glaciation of the volcanic slopes of Martin and Mageik, and with the great flood of 1915 became mixed in all proportions with the ash and pumice of the upper Katmai, and spread along the western side of the river valley. Towards the river the black sand content gradually diminishes until the soil becomes a pure mixture of ash and pumice. The loose texture of this river deposited material was in striking contrast to the finely divided, compact ash of the lower stretches, and offered a soil where physical conditions appeared ideal for the growth of seedling plants. Nevertheless the only plant taking advantage

*Photograph by R. F. Griggs*

A LUPINE GROWING ON THE ASH FLAT.

Although the soil is almost devoid of nitrogenous compounds as shown by the analysis, the lupines thrive and produce seed in abundance.

of these conditions was a legume, *Lupinus nootkatensis*. These plants were quite numerous and apparently were normal and healthy, having produced an abundance of ripened seed by the middle of August. Those growing farthest out on the ash were somewhat stunted in growth, but this was not to be wondered at considering that they had to withstand the buffetings of many a fierce sandstorm in which their lower leaves were cut to pieces by the sharp wind-driven volcanic ash. All of the lupines examined had an abundance of nodules on their roots. These must have been the source of their nitrogen for

there was nothing like sufficient total nitrogen, much less water soluble nitrogen, present in the ash for the sustenance of the plants. Here we have Hellriegel's famous pot experiments carried out by Nature in the field on an extensive scale. Cultivated soils seldom have less than 100 parts per 100,000 of total nitrogen in the surface foot. Here the total nitrogen content was less than one per cent. of this amount, and the water soluble ammonia and nitrite content almost nil. The presence of healthy lupines growing far out on this ash flat clearly indicates that all of the essential plant constituents were present in the soil, while the absence of all other varieties of plants pointed to

*Photograph by R. F. Griggs*

THE PUMICE FLAT ON WHICH LUPINES ARE STARTING.

The dark spots right and left are lupine plants similar to that shown close up on the opposite page. The entire absence of all other vegetation is very striking.

the lack of some essential constituent of plant growth. This essential was no doubt nitrogen. The lupines were doubtless provided with their necessary nitrogen by symbiotic relations with the nitrifying bacteria in the nodules.

The first four determinations in Table IV show that the growing plants have not altered the ammonia and nitrous nitrogen content of the ash. Those determinations on the original black soil, where plants were growing in profusion, indicated almost the complete absorption of all the ammonia

and nitrous nitrogen. The total nitrogen of these latter samples would of course have shown a total nitrogen content comparable to that of (13), Table V.

That the lupines were not found growing in profusion up over the ash covered hills is probably due to the lack of inoculation with nitrogen fixing bacteria of any seeds that may have found their way onto the surface. The river bed ash has been water transported and thus probably become inoculated with bacteria from the pre-eruptive soil, but the ash upon the hillsides is lying as it fell five years ago.

TABLE V.

NITROGEN CONTENT OF TUNDRA, KASHVIK BAY, ALASKA.

| 1917 | Parts Nitrogen per 100,000 NH₃ | NO₂ | Total N. |
|---|---|---|---|
| June 20. (1) Surface sample among roots | 0.120 | none | ..... |
| June 20. (2) Sample 6″ beneath (1) | 0.240 | 0.0012 | ..... |
| June 20. (3) Sample 18″ beneath (1) | 0.240 | 0.0012 | ..... |
| June 21. (4) Surface sample among roots | 0.360 | none | ..... |
| June 21. (5) Sample 8″ beneath (4) | 0.060 | 0.0006 | ..... |
| June 21. (6) Sample 24″ beneath (4) | 0.120 | 0.0006 | ..... |
| June 21. (7) Northerly slope, surface among roots. | 0.096 | none | ..... |
| June 21. (8) 15″ beneath (7). Tundra frozen below | 0.160 | 0.0002 | ..... |
| June 21. (9) 18″ beneath (7). Frozen tundra | 0.064 | 0.0004 | ..... |
| June 22. (10) Sample from hollow in tundra, bare of vegetation | 0.180 | none | ..... |
| June 22. (11) 18″ beneath (10). On surface of sandstone rocks | 0.162 | none | ..... |
| Aug. 22. (12) Surface sample of tundra | 0.160 | trace | ..... |
| Dec. 19. (13) Sample from first foot of tundra | ..... | ..... | 432.0 |

## THE NITROGEN CONTENT OF ALASKA TUNDRA.

An opportunity for studying the nitrogen content of the tundra was offered at our Base Camp on Kashvik Bay. The tundra here is very shallow, seldom more than a couple of feet in depth, and rests upon the decayed sandstone rocks of Jurassic age. Small depressions occur at intervals, exposing the sandstone rocks below. Clumps of cottonwood and alder stretch up the mountain slopes, while down toward the sea the tundra is almost bare of large shrubs, but covered with a more or less rank growth of grass and small flowering plants. Narrow, invisible streams cut the tundra to the sandstone bed and run down to the sea.

The ammonia content of the tundra is about that of a normal soil. Ordinary soils contain little ammonia, usually from 0.2 to 0.8 parts of nitrogen per 100,000. Rich garden soils may contain up to 2 parts per 100,000, while Boussingault reports 50 parts in leaf mould from South America. Peat has been found to contain as high as 18 parts per 100,000.

The nitrite content is much higher than that found in the samples of ash. The surface tundra has no nitrites, as was to be expected in an area well under-drained and subjected to frequent rains. The nitrite forming bacteria do not operate near the surface but are found in the deeper, darker layers. The presence of much vegetable matter in the tundra, upon which the nitrifying bacteria may work, accounts for the greater proportion of nitrous nitrogen over that found in the ash.

On the northerly slopes the winter frost had not left the tundra by June 21st. Determinations made on the frozen tundra did not indicate any marked difference between its ammonia and nitrous nitrogen content and that already thawed out. Nitrification is rather feeble at temperatures below 5° C, and only begins to be really active at 12° C. A determination made on August 22nd gives no indication of any material change in the rate of nitrification with the season. Evidently the cold condition of the tundra produced no change in the nitrite content throughout the long frozen period.

The total nitrogen content of the tundra, 432 parts per 100,000, is considerably higher than that of the average cultivated soils. Illinois prairie soils contain 308 parts per 100,000, while the abnormally high nitrogen content of the rich black loam of the Red River Valley, in the neighborhood of Winnipeg, contains but 373. This large total nitrogen content is probably associated with a low rate of nitrification in the cold, shallow soil of the tundra.

Manitoba Agricultural College, Winnipeg

SCIENTIFIC RESULTS OF THE KATMAI EXPEDITIONS OF THE NATIONAL GEOGRAPHIC SOCIETY.

## VI. THE WATER SOLUBLE SALT CONTENT, THE FERROUS IRON CONTENT AND THE ACIDITY OF KATMAI VOLCANIC ASH.

J. W. SHIPLEY,
Chemist of the 1917 Expedition.

Certain samples of Katmai volcanic ash collected by Dr. R. F. Griggs in 1916 were found by him not to support the growth of plants, but on the contrary apparently to have a toxic effect upon germinated seedlings. Qualitative tests made by the author upon these samples indicated the presence of ferrous sulphate together with a decided acidity in the water extract. During the expedition of 1917 other samples of ash were collected from deposits upon which vegetation had secured a more or less precarious hold, and in which field observations showed acidity in conjunction with the presence of ferrous iron. These samples were analyzed with the object of ascertaining whether the acidity and ferrous iron content was sufficient to account for the apparent sterility.

SAMPLE NO. 1. Stream deposited ash from near Katmai Church at the mouth of Katmai River, collected in 1916. Sample 33, Vegetation Station No. 102. Wheat germinated, but the seedlings quickly became malformed and never appeared above the surface. For determination of nitrogen content, see page 218.

SAMPLE NO. 2. Katmai Mud Flow on Katmai Volcano, collected in 1916. By itself it was toxic to wheat, but this toxicity was removed when it was mixed with coarse sand.

SAMPLE NO. 3. Katmai Mud Flow, collected in 1917.

SAMPLE NO. 4. Pillar Mountain Station, Kodiak Island. Vegetation Station No. 14. Collected in 1917. Plants not growing.

SAMPLE NO. 5. Katmai River mud, deposit above Camp II. Seedling grass growing. For nitrogen content see page 218.

SAMPLE NO. 6. Similar to No. 5, and close to it, but seedling grass had died. For nitrogen content see page 218.

The analysis was carried out on 100 gram samples of the air dried ash. This amount of each sample was placed on a filter paper in a funnel and lixiviated with successive portions

of hot water, until the filtrate approximated 500 cubic centimeters. This water extract was then made up to exactly 500 cubic centimeters and 100 cubic centimeter portions used for the analysis. The acidity was determined by titration against N/100 NaOH and calculated as $H_2SO_4$, the ferrous iron by titration against N/20 $KMnO_4$. The ferric iron was also determined in Samples No. 1 and No. 6 by reduction with zinc and sulphuric acid and titration against $KMnO_4$. The

*Photograph by D. B. Church*

FLOOD BORNE SILT AROUND KATMAI CHURCH.

This appeared to be a favorable situation for the beginning of revegetation, but it was found by experiment that the soil was toxic to wheat plants. The analysis showed 0.558% of ferrous iron.

increase in the amount of $KMnO_4$ used in this titration, over that in an equal volume before reduction, gave a measure of the ferric iron. The water soluble sulphate was also determined in these two samples by precipitation as $BaSO_4$. The accompanying table contains the results of the analysis.

Ferrous sulphate is not only directly injurious to plant growth, but by inhibiting the action of nitrifying bacteria indirectly cuts off the supply of an essential food. The presence of this toxic compound, together with the low nitrogen content

of the Katmai ash, will militate strongly against the revegetation of the areas affected. Ferrous sulphate in the presence of water hydrolyzes, giving ferrous hydroxide and sulphuric acid. Nitrifying bacteria do not thrive well in a strongly acid medium. The presence of 1.35% FeO ($FeSO_4$ calculated as FeO) kills all nitrifying bacteria, while 0.3%, according to Storer[1], is very injurious. Voelcker found that 0.5% $FeSO_4$ did much harm to plants, while 1.0% killed entirely.

TABLE I.

WATER SOLUBLE FERROUS IRON CONTENT AND ACIDITY OF KATMAI VOLCANIC ASH.

| SAMPLE NO. | 1 % | 2 % | 3 % | 4 % | 5 % | 6 % |
|---|---|---|---|---|---|---|
| Acidity as $H_2SO_4$..... | 0.215 | 0.020 | 0.014 | 0.003 | 0.025 | 0.057 |
| Ferrous Iron as FeO.. | 0.558 | 0.063 | 0.040 | 0.081 | 0.180 | 0.270 |
| Ferric Iron as $Fe_2O_3$.. | 0.037 | ..... | ..... | ..... | ..... | 0.025 |
| Sulphate as $SO_4$...... | 0.300 | ..... | ..... | ..... | ..... | 0.081 |

The toxic effects of Samples No. 1 and No. 6 are no doubt attributable to the ferrous iron content, while Sample No. 5 is probably a poor soil for the growth of most plants. In fact, the seedling grass observed on it was far from healthy and strong. A low nitrogen content, of course, would prevent any rank growth, and this Sample No. 5 also possesses. The Katmai Mud Flow does not possess sufficient ferrous sulphate to injure plant development and consequently, as Dr. Griggs found, wheat would germinate and grow when the ash was brought into proper physical condition by the addition of coarse sand.

The soluble sulphate content of the samples analyzed is not sufficient to combine with all the iron present. There was a certain amount of chloride present in the samples, but a quantitative estimation of this acid radical was not made. The ratio of sulphate to iron in the two samples analyzed is practically the same.

The presence of water soluble ferrous iron in the above samples is probably directly attributable to the volcanic origin of the ash. Ferrous iron in marshland and moors is attributed to the reducing action of algæ upon sulphates, but here, although the soil was wet, algæ were not in evidence to any extent, and surface water conditions could hardly be considered as stagnant.

[1]Storer, F. H. Agriculture in Some of its Relations to Chemistry, Vol. 2, page 209. 1906.

The conditions of the eruption were reducing, and sulphuretted hydrogen, together with hydrochloric acid, are still important volcanic emanations of this region. The ash contains considerable quantities of ferrous iron, and this acted upon by the acid fumes would give water soluble ferrous iron. Some of the streams leaching the slopes of Mt. Katmai are strongly impregnated with alum, indicating plenty of sulphates in the ash deposit. The finely divided, water deposited ash of Samples No. 1 and No. 6 are very compact and practically impervious to atmospheric oxygen; consequently the iron has had little opportunity to pass to the ferric condition. Moreover, the absence of humus and of soluble calcium salts prevents the fixing of the toxic ferrous iron into compounds non-injurious to plant growth.

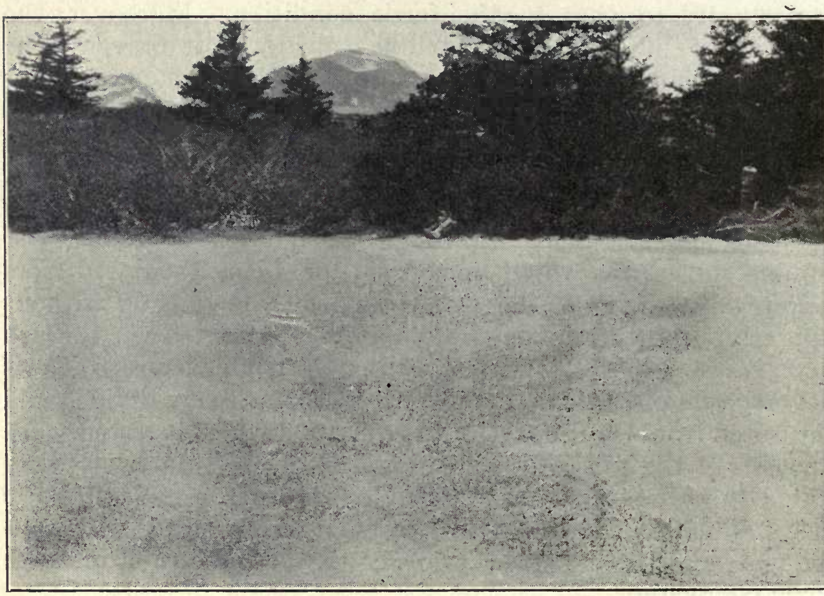
Numerous observations in the field showed that ferrous iron and acidity were always associated with finely divided, river deposited ash saturated with water. This formed a compact impervious mass, through which an exchange of water soluble substances would not occur; for, being saturated from below, any rainfall on its surface immediately runs off without appreciably affecting the content of the mass. Even the ash deposit on Pillar Mountain, although wind deposited, was nevertheless of this character, for it was very finely divided and saturated from the seepage of the hill upon which it rested. All deposits of the ash, where composed of coarser materials, were found to be free from water soluble ferrous iron and sulphuric acid. This was no doubt due to efficient drainage, with consequent aeration and prevention of the accumulation of these toxic compounds.

## THE WATER SOLUBLE SALT CONTENT OF KATMAI VOLCANIC ASH.

The water soluble salt content of a number of samples of the Katmai volcanic ash was determined by the Electrical Bridge, according to the method recommended by Davis and Bryan[2], for the determination of alkali in soils. The measurements were carried out on samples of the ash, treated with distilled water, until just a little more than saturated. The instrument used was the latest form of the Electrical Bridge, as described by Davis and Bryan in the above mentioned bulletin, and the calculations for the salt content from the Bridge readings were based on their factor 1.45 as the ratio

[2]Davis, R. O. E. and Bryan, H. The Electrical Bridge for the Determination of Soluble Salts in Soils. U. S. Dept. of Agriculture, Bureau of Soils, Bull. 61 1910.

of soil resistance to solution resistance. The use of this factor was made necessary since the table of resistances and salt content did not cover the whole range desired. A series of resistances for sodium chloride solution, ranging from 0.5 grams to 2500 grams per 100,000 of water was determined on the Bridge, and by using the factor 1.45 and interpolating, the results given in Table II were obtained. No great degree of accuracy is claimed for the results, but the measurements are roughly approximate, and give some idea of the soluble salt content in the volcanic ash deposits. Included in the table are two



*Photograph by R. F. Griggs*

DEPOSIT OF BARE ASH ON PILLAR MOUNTAIN, KODIAK.
Determinations of ferrous iron, acidity, soluble salt content, ammonia, nitrite and total nitrogen content of this ash were made.

measurements made with the same instrument on arable soil, the samples being representative of the first six inches. The Katmai River wash, where finely divided, contains a much higher salt content than the normal soil or the coarse deposits, such as those of the Martin Creek flat. The ash from the wind blown drift on Pillar Mountain contains very little soluble salt content, a factor possibly entering into the non-fertility of this deposit. The two samples from the Katmai Mud Flow show very little variation, although a twelvemonth elapsed between the collections. The very fine upper layer of ash, as collected

from the slopes of Katmai, shows a relatively high water soluble content, 39.2 parts per 100,000. This finely divided, compact layer does not leach out so readily as the coarse material of the lower layers, and consequently will hold its salt content more tenaciously.

A comparison of the total water soluble salt content, as determined by the Electrical Bridge, with the ferrous iron content, as determined by successive leachings and titration with $KMnO_4$, shows a wide divergence in the cases of Sample 33 and the Pillar Mountain drift. The total water soluble content does not nearly approximate the ferrous iron content as calculated from the reducing property of the leachings. This would

TABLE II.

Soluble Salt Content of Katmai Ash. Calculated from the Electrical Resistance.

| | Resistance at 60° F. Ohms | Calculated Salt Content per 100,000 Grams |
|---|---|---|
| (1) Sample 33. Stream deposited ash, Katmai Church. Wheat would not grow | 256 | 92.0 |
| (2) Katmai Mud Flow. 1916 | 684 | 29.1 |
| (3) Katmai Mud Flow. 1917 | 673 | 30.0 |
| (4) Ash, Pillar Mountain Station, Kodiak | 4218 | 5.7 |
| (5) Katmai River wash. Seedlings growing | 162 | 195.0 |
| (6) Katmai River wash. Seedlings died | 136 | 230.0 |
| (7) Sample 37. Generalized sample of ash as it lay on the ground after three years weathering, Kodiak, August, 1915 | 196 | 160.0 |
| (8) Sample 38. Wind blown ash, collected in attic, Kodiak | 388 | 53.5 |
| (9) Ash from around roots of lupine, Martin Creek flat | 1344 | 15.6 |
| (10) Top layer ash, 2000 feet up Katmai Volcano | 558 | 39.2 |
| (11) Tundra, Kashvik Bay | 826 | 19.0 |
| (12) Red River Valley black loam, timothy growing | 445 | 48.2 |
| (13) Red River Valley black loam, oat field | 515 | 43.0 |

indicate that the ferrous compound, whatever it may be, either does not go readily into solution or does not dissociate. The agreement between the results in the case of the remainder of the samples included in Table I and those in Table II is much closer. Although a considerable range of water soluble salt content in the various samples of ash is seen to exist, yet the divergence from that of a normal soil is not so marked as one might expect, the content from the normal soils listed lying intermediate between the extremes of the ash samples. Even the high water soluble salt content of (1), (5), (6) and (7), in Table II, is not so high as that of some alkali soils on which crops grow and mature.

SCIENTIFIC RESULTS OF THE KATMAI EXPEDITIONS OF THE NATIONAL GEOGRAPHIC SOCIETY.

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# VII. AMMONIA AND NITROUS NITROGEN IN THE RAIN WATER OF SOUTHWESTERN ALASKA.

J. W. SHIPLEY,
Chemist of the 1917 Expedition.

While engaged in the work of the 1917 Katmai Expedition of the National Geographic Society, directed by Dr. R. F. Griggs, opportunity was afforded for making observations on the ammonia and nitrite content in the rainfall of Katmai and adjacent districts. Determinations were made on the Bering Sea side of the peninsular axis, on the Pacific slope, and on Kodiak Island, 100 miles to the eastward. The most extended series of observations was made at our Base Camp on Kashvik Bay, during a very rainy period from August 19th to August 27th. This constitutes the major part of the work done and the results, together with those of Kodiak Island, are to be found in the accompanying Table. Kashvik Bay is on Shelikof Strait, about 25 miles due south of Katmai Volcano and the same distance southeast from the Valley of Ten Thousand Smokes.

The chemical reagents, brought with the expedition for determining ammonia and nitrites in the volcanic ash, were equally well adapted for measuring the same nitrogen bearing compounds in rain water. Ammonia was determined by color comparison with Nessler's reagent, using a standard solution of ammonium chloride. The nitrites were compared with a standard solution of sodium nitrite through Greiss's reagent, (a naphthylemine and sulphanilic acid). These solutions were prepared according to the A. P. H. A. Standard methods of Water Analysis. On returning from the expedition the standard solutions were compared with freshly prepared solutions of the same salts, using the reagents brought back from Alaska. The $NH_4Cl$ proved to be unchanged, but the $NaNO_2$ had decomposed 50%. A sample of the same nitrite solution, as taken on the expedition, but left in a dark cupboard in the laboratory, had also decomposed to the same degree. The solutions were

prepared May 16, 1917, and were compared on December 19th, seven months later. A comparison made on May 22, 1918, showed a further decomposition amounting to an additional 15%. Assuming that the decomposition followed the law of mass action, corrections were applied to the field determinations, and the results tabulated are the corrected observations.

The necessity for preparing distilled water was fortunately obviated by the almost total absence of either nitrous nitrogen

TABLE.

AMMONIA AND NITROUS NITROGEN IN RAIN WATER OF SOUTHWESTERN ALASKA.

| Place | Collection | Analysis | Parts Nitrogen per 100.000 | | Remarks |
|---|---|---|---|---|---|
| Base Camp Kashvik Bay | | | $NH_3$ | $NO_2$ | |
| (1) | Aug. 19 | Aug. 22 | trace | 0.0008 | Stood in covered aluminum pail. |
| (2) | Aug. 15–22 | Aug. 22 | 0.03 | 0.001 | In brass rain gauge for almost a week. |
| (3) | Aug. 19 | Aug. 25 | trace | 0.0004 | Same sample as (1). |
| (4) | Aug. 25 | Aug. 25 | trace | 0.0003 | Rain gauge ¾″ fall. N. E. storm. |
| (5) | Aug. 25 | Aug. 25 | trace | 0.00035 | Glass funnel and Nessler tube. |
| (6) | Aug. 25 | Aug. 25 | trace | 0.00016 | Later in day, rain gauge. |
| (7) | Aug. 25 | Aug. 25 | trace | 0.00014 | Same time as (6). |
| (8) | Aug. 26 | Aug. 26 | trace | 0.00012 | Funnel, in morning. |
| (9) | Aug. 26 | Aug. 26 | none | none | Funnel, in afternoon near end of rain. |
| (10) | Aug. 25–26 | Aug. 26 | 0.0015 | 0.00016 | Rain gauge, storm from over Shelikof Strait. |
| (11) | Aug. 27 | Aug. 27 | none | 0.0003 | Funnel, ¼″ fall, no wind. |
| (12) | Aug. 27 | Aug. 27 | none | 0.00018 | Rain gauge, same as (11). |
| Kodiak | | | | | |
| (13) | Sept. 15 | Sept. 15 | trace | 0.00014 | Off metal roof, N. E. Storm. |
| (14) | Sept. 15 | Sept. 15 | trace | 0.00016 | Collected in aluminum pail. |

or ammonia nitrogen in the spring and creek waters of the district, and in water obtained from melting snow. At Kashvik Bay no coloration whatever was produced by Nessler's reagent in the water from the creek. On adding to 50 cubic centimeters of the creek water 0.05 cubic centimeters of the standard $NH_4Cl$ solution containing 0.00001 grams nitrogen per cubic centimeter, a distinct coloration was produced, and on diluting to half this concentration the solution was more strongly colored than an equal volume of creek water. A similar test, using the standard $NaNO_2$ solution proved the almost entire absence of nitrites in the water of the creek.

In addition to water collected in the rain gauge, use was made of an aluminum pail and glass funnels set in the mouth of 50 cubic centimeter Nessler tubes. The latter proved to be the most serviceable. The collections at Kashvik Bay were made over the tundra, not less than eight inches above the vegetation in the case of the funnels, and almost two feet in that of the rain gauge. The Nessler tubes were always rinsed with the first fallings. Excepting the rain gauge, collections were made to the windward of camp, and far enough removed to prevent the possibility of contamination from the occasional camp fire.

The two determinations made at Kodiak were during the progress of a heavy northeasterly storm, lasting the entire day. Sample (13) was collected about mid-day, while (14) represents all but the beginning of the rain. Due to the direction of the wind, no contamination from smoke was possible.

The first three determinations in the Table were made on samples standing for some time after collection. The high nitrite content of these three is probably associated with this long standing. The high ammonia content of (2) was the result of small twigs and pieces of bark, wind-driven into the exposed rain gauge during the previous week.

The almost entire absence of ammonia in the rainfall of southwestern Alaska is in striking contrast with that found at a similar latitude in Europe. The average of a number of observations in Scotland gave 0.61 parts of ammonia nitrogen per million on the seacoast, and 0.44 parts at inland country places, while Glasgow gave 7.49 parts per million. The highest observed at Kashvik Bay was 0.015, and in most cases there was but a mere trace if any. At the Experimental Station, Rothamsted, England, the average of ammonia nitrogen in rain water over a fifteen year period was 0.45 parts per million. Storer states that the average in regions where factories are absent is about 0.02 parts per million.

Nitrous nitrogen was positively present in every determination excepting (9). The presence of even the small quantity of nitrites represented by the Table, in the rain water of a region devoid of thunderstorms, is highly interesting. One might expect that all nitrites would be transformed into nitrates in the presence of such oxidizing agents of the atmosphere as ozone

and hydrogen peroxide. But instead, nitrites were found to the extent of 0.0035 parts per million of rain water at the beginning of a rainfall.

The rainfall of August 25th-26th shows a gradual falling off in nitrite content as the storm progressed, until towards the end none was observed. The content in the rain gauge throughout the storm is the average of that found at the beginning and at the end, as well as the average of all five samples collected in the funnels. It is also to be noted that the nitrite content had again risen to the maximum in a quarter inch rainfall the very next day, while the ammonia content still remained at a minimum.

One further peculiar circumstance was observed, in that, on standing for about four hours in the Nessler tubes, the reddish color produced in the samples of rain water faded out, while those in the standard solution of creek water retained their color.

The observations made on the Bering Sea side of the peninsular axis were quite irregular in the amount of ammonia and nitrite found. The determinations were carried out at Camp V in the Valley of Ten Thousand Smokes, just at the western entrance of Katmai Pass. When the wind blew from over the Valley, the ammonia and nitrite content was relatively high, while only traces were observed when the storm was blowing into the Valley. The rainfall, when the wind blew from over the Valley, also contained notable quantities of chloride and sulphate, and at times was so strongly acid as to make the eyeballs smart. Samples of rain water were collected close to fumaroles, so that the rain fell through ascending gases. Many of these gave so much ammonia that a heavy yellow precipitate formed with Nessler's reagent. The quantity of nitrous nitrogen was also greater than in an ordinary rainfall, and one fumarole in particular gave a deep red color, indicating the presence of considerable quantities of nitrites in the gaseous emanation. Quantitative comparisons were not made excepting in the cases when the storm was blowing into the Valley. Here, as already stated, the ammonia and nitrite content differed but little from that observed at Kashvik Bay.

Water from melted snow was used for the standard solutions. The drip from the snow bank was remarkably free from ammonia and nitrites, although these were being poured

forth from the millions of fumaroles in the immediate neighborhood. Air, laden with these products, was constantly in contact with the thin layer of ash above the snow, and the frequent rains must have carried them down into the snow beneath. Nevertheless, melted snow from the bank behind Camp V gave no positive test for either ammonia or nitrite during the whole month we were in the Valley. Rain Water collected above the snow bank, when the wind blew from over the Valley, gave considerable quantities of both. This freedom from ammonia and nitrites was also observed in water from a snow bank on Observation Mountain at the eastern entrance of Katmai Pass. Here the bank in question was covered by several feet of ash, and was highly discolored from the leaching due to frequent rains. This bank served as a source of water for the standard solutions used in the comparison cylinders at Camp IV. One possible explanation for the absence of these nitrogenous substances is the presence of organisms in the snow capable of utilizing the ammonia and nitrite content of rain water in their assimilative processes.

A sample of rain water collected by hanging an aluminum pail from the dead branch of a tree gave an unusually large content of ammonia. The only contamination apparent was the drip from a short section of this one small dry branch. Water, in which a few twigs broken from the same cottonwood tree were allowed to stand for a short time, gave a heavy yellow precipitate with Nessler's reagent, proving that the high result noted above came from ammonium or similar nitrogen compounds in the decaying wood. The soil must receive considerable additions of ammonium compounds washed down from decaying trees, and in this region, where the lack of nitrogenous material for plant growth is so marked, this source of nitrogen may have some little influence on the revegetation of the destroyed area.

Manitoba Agricultural College, Winnipeg.

Scientific Results of the Katmai Expeditions of the National Geographic Society.

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# VIII. A STUDY OF TEMPERATURES IN THE VALLEY OF TEN THOUSAND SMOKES.

Jasper D. Sayre and Paul R. Hagelbarger.

The most serious failure of the expedition of 1917 was its inability to measure the temperatures of the volcanoes in the Valley of Ten Thousand Smokes. The Smokes were so much hotter than had been anticipated that the expedition found itself without the apparatus necessary for their measurement. An ordinary mercury thermometer, registering up to 350° C., was all that had been provided. The top of this was soon broken, but before this accident occurred, it had been discovered that many of the temperatures were beyond the range of this instrument, or at least so near the limit of its readings that it was not considered safe to immerse it in the hot vapors long enough to allow the mercury to expand fully for fear of bursting the tube.

One of the principal objectives of the Expedition of 1918, which was undertaken by the authors, was therefore the study of the temperatures of the vents in the Valley.

In this project, as well as in the chemical study of the volcanic gases, the expeditions were aided by the Geophysical Laboratory of the Carnegie Institution, which undertook to supply the necessary equipment. But on account of the war considerable difficulty was experienced in securing the requisite instruments. Potentiometers of the Leeds and Northrop type were not to be had. It was indeed by the narrowest margin that any pyrometers were obtained at all. Up to within twenty-four hours of the departure of the expedition we had not succeeded in obtaining any instruments whatever. But on the last day a pyrovolter from the Pyrolectric Instrument Company, of Trenton, New Jersey, and a pyrometer from the Hoskins Manufacturing Company, of Detroit, arrived.

Although such hasty tests as could be made amid the hurry of the last preparations for departure indicated that both instruments were in working order, it was not possible to gain


Photograph by C. F. Maynard

LOOKING SOUTHWEST FROM STATION IX ACROSS THE VALLEY.

Showing the location of Fumaroles 29, 30, 31, 32, 33, 34, 35, 36, 37, 45.

that acquaintance with their behavior nor to test the accuracy of their readings, which everyone will recognize as highly desirable preliminaries to the use of any instruments.

But notwithstanding these handicaps, the instruments did good service in the field, giving identical and apparently trustworthy readings at all times. At the beginning of the work their readings were compared in the vapor of Fumarole No. 1, which was convenient to our camp; and again at the close of the season, when checked at the same vent, they gave the same readings as at the beginning, thus allowing us to repose confidence in their readings throughout.

Two months later, when they were unpacked after being returned to Columbus, it was observed that, while the Hoskins instrument was apparently still in good order, the battery (dry cell) of the pyrovolter had completely gone bad. They were then repacked and shipped to the Geophysical Laboratory where they were recalibrated by E. D. Williamson, who reported as follows:

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| "Temperature, | 448, | 444, | 441, | 433, | 351, | 348, | 254. |
| Reading (Hoskins Instrument), | 458, | 453, | 450, | 443, | 359, | 355, | 259. |
| Reading (Pyrovolter), | 441, | 442, | 441, | 438, | 348, | 343, | 255. |

"The readings in the first row were taken with Pt. Rh. thermoelement. You will notice that the Hoskins combination reads consistently about 2% too high, while the other is less consistent, but does not involve errors greater than the expected accuracy permits. We found that the battery in the pyrovolter was completely used up, but hope that this did not affect any of your readings.

"The two thermometers were calibrated at the boiling point of water, where each read 0.3° too low."

Following this report the readings observed in the vents have been corrected to accord with the recalibration. Because of the great variations encountered from place to place in a column of escaping gas it was not considered advisable to attempt to read the instruments closer than the nearest 5°. Where the correction is applied the resultant temperatures are usually expressed by an intermediate figure. They are recorded as they came out after correction, but such temperatures, as for example 299° C., would be best considered as 300° C., for no implication that the errors are less than 3° either way is intended.

The method of procedure in the field was, starting out in the morning with packs containing thermometers, one or both pyrometers, 5 x 7 camera, Kodaks, spade and other necessary


*Photograph by C. F. Maynard*

LOOKING SOUTH ACROSS THE HEAD OF THE VALLEY FROM BAKED MOUNTAIN.

Showing the location of Fumaroles 5, 8, 9, 14, 15, 16, 17, 18, 19, 20, 21.

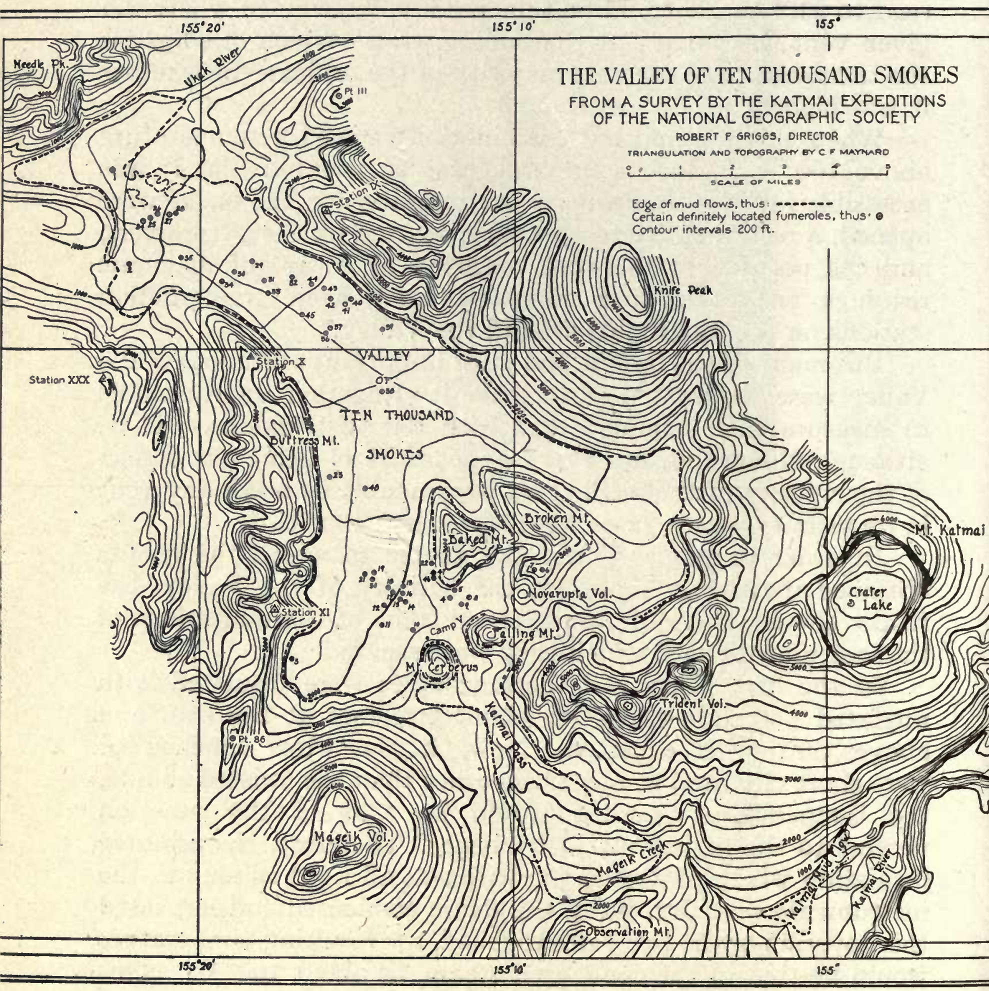
equipment, to proceed to examine all vents in the area selected for study. It was our custom to proceed rapidly, giving the vents a preliminary examination with a thermometer which read to 210° C. It could be thus readily determined whether a given vent was merely at the boiling point—which of course is the temperature of the vast majority of the orifices—or whether it was higher.

When this preliminary examination showed a temperature above 100° C., and the fumarole was so situated that it was accessible for measurement by our instruments, the packs were opened, a record of the temperature secured by the pyrometers, and the position of the vent recorded by means of magnetic readings on a Brunton compass, from fixed triangulation stations on the mountains around the Valley.

But many of the largest and most important volcanoes of the Valley were so situated as to make it altogether impracticable to measure their temperatures with our instruments. Thus, although Novarupta has every appearance of being the climax of the activity of the Valley, we were unable to reach any vent in its vicinity whose gases were more than 100° C.

In order to judge rightly the degree to which the results obtained may truly represent the activity of the Valley, the reader should, therefore, understand some of the limitations of the instruments with which they were secured.

In the first place, our thermocouples were insulated with unglazed porcelain tubes for about two feet at the end, and above that with asbestos. Now, if the wires touched or were short circuited at any place other than the twisted couple, the temperature recorded would be that of the junction nearest to the registering instrument. Therefore, the asbestos insulation which protected the wire was all right as long as the instruments were dry, but if the steam condensed and saturated this covering or the two wires touched, the resulting temperature would be that of the condensed steam, or about 100° C. This occurred frequently because the steam would condense where it came in contact with the cold air at the side of the hole. We overcame this by bending the wires so that they did not touch each other while in the steam. As almost every fumarole necessitated a different bending of the wires, the asbestos insulation and porcelain tubes were subjected to considerable wear and tear.


THE VALLEY OF TEN THOUSAND SMOKES
FROM A SURVEY BY THE KATMAI EXPEDITIONS
OF THE NATIONAL GEOGRAPHIC SOCIETY
ROBERT F GRIGGS, DIRECTOR
TRIANGULATION AND TOPOGRAPHY BY C F MAYNARD
SCALE OF MILES
Edge of mud flows, thus:
Certain definitely located fumeroles, thus:
Contour intervals 200 ft.
155°20'
155°10'
155°
Needle Pk.
Ukak River
Pt III
Station IX
Knife Peak
Station X
Station XXX
VALLEY
OF
TEN THOUSAND
SMOKES
Buttress Mt.
Broken Mt.
Baked Mt.
Novarupta Vol.
Mt. Katmai
Crater Lake
Station XI
Camp V
Falling Mt.
Mt. Cerberus
Trident Vol.
Katmai Pass
Pt. 86
Mageik Vol.
Mageik Creek
Katmai Mud Flow
Katmai River
Observation Mt.

The same thing was apt to happen if the two wires were allowed to rest on the wet ground, as the steam usually kept the ground around the fumaroles damp. We therefore supported the wires on some object, such as a spade or a pole. The porcelain tubes, too, would sometimes collect the condensed steam and short circuit the instrument. As the two wires went through perforations in the same tube, the only remedy for this was to allow them to dry out again if they became saturated with water. This was usually accomplished by allowing the thermocouple to remain in some hot fumarole for a considerable length of time. As one had to thrust the wires from the cold air into the hot steam, more or less condensation always occurred. If the fumarole was above 200° C. the condensation would not be very great and the tubes would quickly dry out, but if it was just above the boiling point, so much water would condense that we would get a temperature of only 100° C. As a result, we obtained very few temperatures just above the boiling point, because we did not wait long enough for the tubes to dry out or because the temperature was not high enough to dry them out. Out of the 48 fumaroles, or areas of fumaroles, we studied, only six were found which registered between 100° C. and 190° C.

Many of the fumaroles of the Valley were inaccessible to us with the instruments which we had. The thermocouple of the pyrovolter, which was six feet long with 50 feet of lead wire, was made of such small wire that it would not support its own weight, so we had to attach it to a long pole. This complicated matters considerably, for if we used wire to fasten it on, the insulation would quickly burn through in hot fumaroles and short circuit the wires, and if we used string, rope or something of that nature, it was very soon burned off. Besides, the pole served as a collector of steam and, although the wires did not touch, they were short circuited by the steam, especially at the point of contact of the cool air and the hot gases. The only practical and satisfactory way in which we could use this six foot thermocouple was for lone fissures or cracks not surrounded by an area of steam, where the temperature at the surface or six inches down was required. It was in these places that we used it to check up the readings of the pyrometer.

The thermocouple of the Hoskins pyrometer was 10 feet long with 30 feet of lead wire. At the end used in the hot gases,

the wires were simply twisted together and welded in a high temperature furnace. The other end, from which the lead wires ran to the recording instrument, was covered with a wooden handle. This end, the cold junction, was connected with a small open coil of fine insulated wire inside the handle and had to be kept at the air temperature the same as the recording instrument, as well as dry and clean. This limited the use of the thermocouple to a length of eight feet in a hole. In many cases the steam around the vents was so thick as to prohibit its use at all. We partly overcame this in some cases by wrapping the cold junction in a towel to keep the steam from condensing in the coil. While this limitation made no difference in narrow throated fumaroles, it was a serious handicap in dealing with large crater-like vents where one could see for 50 or 60 feet down the hot throat. In one of the "Twins," for example, where the temperature at the surface was 309° C. we wondered what the temperature would be 60 feet down the hole.

The recording instruments, moreover, had to be kept dry and at the air temperature. The ground for a considerable distance around any area of activity was so hot that correct results could be obtained only by keeping the recording instrument off the ground by setting it on a packsack, sample box or old coat.

Besides these difficulties, there was the personal danger of getting too close to the hot steam, or of breaking through the thin crust over a line of fissures. In many cases we were not able to get near enough to use our instruments at all. If there was a strong and constant wind, we could work quite close to the orifice on the windward side without much danger, but we had to be very careful not to get close enough to produce a back draft or undertow against our bodies. This happened several times in low temperature "steamers." In such cases we had to throw ourselves away very quickly to avoid serious injury, for if one should get into a flare-back from one of those which recorded 300° C., he would be in great danger of terrible injury.

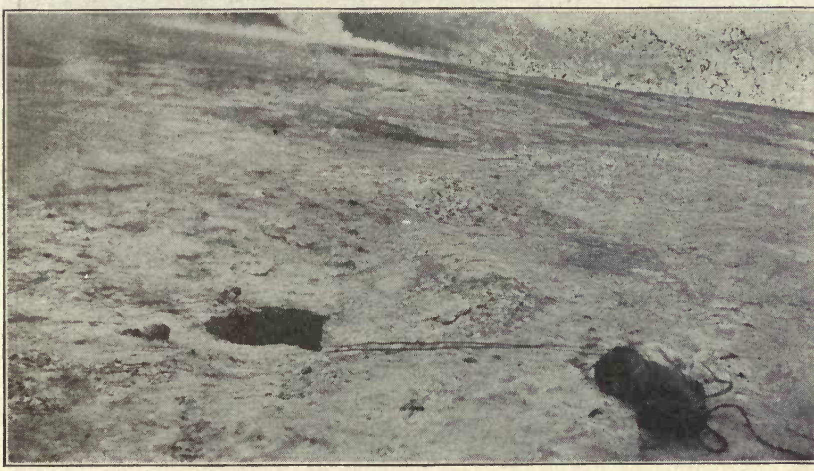
While some of the vents are mild mannered "steamers" emitting principally water vapor, the vapor from others appears altogether dry and consists largely of other gases which are generally disagreeable and sometimes, as for example when heavily charged with hydrofluoric acid,* dangerous if inhaled.

*Analyses of the gases given off from the vents have been begun by Dr. E. S. Shepherd of the Geophysical Laboratory.

Because of the prevalence of strong winds these gases did not interfere with the work as much as might have been expected, but they are an ever present menace and there are considerable areas into which no explorer has yet dared to penetrate for fear of being overwhelmed by the fumes from the thickly placed vents.

### CLASSIFICATION OF FUMAROLES.

Since the fumaroles of the Valley manifest an almost endless variety of form, size and character, it is difficult to find any satisfactory basis for their classification. Nevertheless it will



*Photograph by Jasper D. Sayre*

THE THROAT OF FUMAROLE 5 WITH THE THERMOCOUPLE HUNG DOWN SIX FEET INTO THE HOLE.

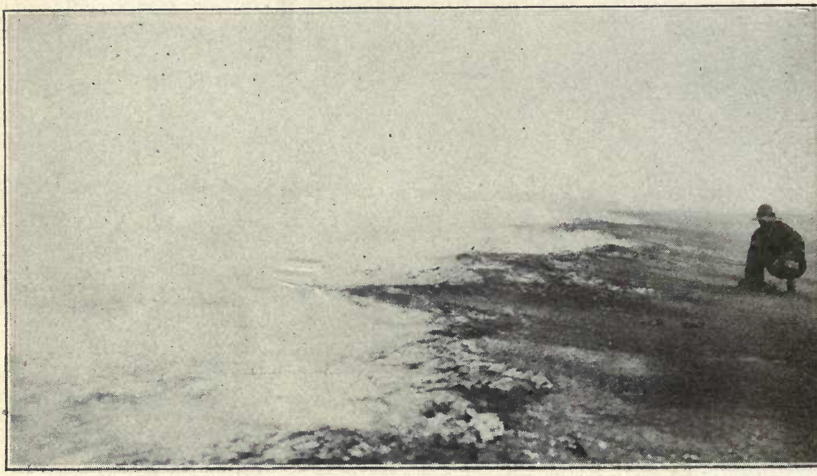
The temperature was 231° C. at this place. The steam did not condense until some distance from the throat. This fumarole is shown from a distance on page 252.

conduce to clearness of thinking to separate them roughly into the following groups. But it must be recognized that there are no distinct lines to be drawn between the different categories, for they intergrade in every way.

1. *Chimneys:* Isolated single holes on the general level of the surrounding Valley floor, with chimney-like throats. There was no surface indication of a lengthy fissure nor of ejecta thrown out around them. The temperature was usually high, (Example No. 5, page 265). These chimney-like fumaroles are

commonly scattered over the Valley. We worked at ten different fumaroles of this type. In this class of fumarole the highest temperature was usually at the surface of the ground, rather than down six or eight feet in the throat. Because of their isolation they were easier to work with than any of the other kinds.

2. *Surface fissures:* Continuous long lines of irregular cracks and crevices, evidently formed in the roofs of lengthy fissures. The surface is baked hard and is conspicuous with its bright deposits and incrustations. The temperature



*Photograph by Jasper D. Sayre*

AREA 29.

By repeated attempts at different fissures in this line of action, we obtained a maximum temperature of 329° C. The surface of the ground was richly colored with incrustations.

was high and the clouds of steam of great volume. These surface fissures are among the most conspicuous and abundant vents in the Valley. They were often 200 yards in length. Occasionally small explosion craters have been formed along the fissures. These have rims of ejecta four or five feet in height and ten feet or so in diameter. The steam was issuing from cracks in their throats, similar to those occurring in the surface of the fissure, (Example, No. 29, page 272).

Surface fissures are the most abundant type of vents in the Valley. Over half the areas which we visited were of this type. Some of them were easily accessible, but, in order to

work others, it was necessary for one man to hold the recording instrument while the other held the thermocouple and moved it from crack to crack. In this way we recorded a number of different temperatures from each area until we found the maximum.

3. *Large steamers:* Large irregular holes resulting from the cave-in of the roofs of wide fissures. They emit a large column of steam under pressure and are very conspicuous and most common near the high mud mark along the edge

*Photograph by D. B. Church*

A PORTION OF THE EDGE OF THE CRATER OF No. 21.

It was impossible to get a satisfcatory photograph of the interior, or to reach the bottom, but a small crack just within the rim gave a temperature of 196° C.

of the Valley. The vent is always large and perhaps much hotter than the temperature which we were able to secure at the edge of the hole would indicate. (Example, No. 22, page 273).

4. *Craters:* Large crater-like orifices, evidently of explosive origin and occurring generally in the floor of the Valley. Many cracks and fissures radiate out from them. They are surrounded by a ring of ejecta rising 15 or 20 feet above the Valley floor and are very conspicuous because of the large amount of steam given off. In no case was it possible to approach the orifice from which the steam emerged to take the tem-

perature, but in one of them (No. 21), we found a temperature of 196° C. in a lateral fissure just inside the rim.

5. *Cracked areas:* Areas with a hard baked surface, much cracked and honey-combed with small fissures. Definite individual vents are rare. The surface cracks are filled with steam coming from below, under considerable pressure. The gases in the steam form a thick deposit on the surface of the mud. They are abundant on the slopes east of Falling Mountain. The emanations from these areas are so copious and they appear so hot and so charged with noxious gases that no one has yet had the temerity to undertake their exploration.

6. *Mud blanketed areas:* Although the general surface of the original mud flow that forms the floor of the Valley has become hard and firm, there are many areas covered with soft, sticky blue mud, which is kept hot by the steam which issues through it in considerable quantity. The activity of these mud blanketed areas takes on one of two forms. Usually it gives rise to myriads of small steam jets best described as *mud hissers*, which come out from indefinite cracks. Although the mud is always blue, the surface is generally covered with a chestnut brown crust which will sometimes support a man's weight. The minute orifices, by which the steam punctures the crust, probably do not constitute permanent vents but presumably shift about rather rapidly. The temperature of the steam and of the surrounding mud was close to that of boiling water. The conspicuousness of these areas varied greatly with the humidity of the air. Although these areas are very common in the center of the Valley, we located only one of them with compass bearings. This one was No. 38, which is the most northerly of these areas in the Valley.

7. *Mud volcanoes:* In some of the mud covered areas the activity produces a more or less violent ebullition, forming mud pots and mud volcanoes. The consistency of the boiling mud varies from a soupy liquid to a viscous mush. The temperature of all was 100° C. We found only two areas of mud volcanoes in the Valley. The first, (No. 48), is in the center of the Valley and is made up of some 15 or 16 crater-like pots. The other area, (No. 44), is located near the northern end of the Valley and containes a line of six very active boiling pots of mud.

8. "*Pimples:*" At the lower (north) end of the Valley where sand storms are frequent, many of the smaller vents have built up conspicuous mounds around their orifices from the wind blown sand, which sticks to their moist surface and becomes a permanent addition to the pile. These mounds, see cut below, vary from six inches to two feet in height. Their temperatures did not exceed 100° C. We found them southwest of No. 24 and north of No. 1 in considerable numbers.

*Photograph by J. W. Shipley*

"PIMPLES" ON THE NORTH END OF THE MUD FLOW.

Near the north end of the mud flow many stratified piles are formed by wind blown ash which is caught and held by the steam from small fumaroles, giving the appearance of pimples breaking out on its surface.

## LIST OF FUMAROLES.

In the list of fumaroles the maximum temperature (corrected) recorded follows the number. Next are given compass bearings on triangulation stations on the mountains around the Valley, whereby fumaroles may be located again with certainty. No attempt has been made to correct for magnetic variation, because the compass is subject to local irregularities which would made correction difficult but do not affect the value of the bearings for relocating the fumaroles, since the irregularities will probably remain sensibly constant for a given station.

The photograph numbers given after the descriptions are the serial numbers of the photographs secured by the expeditions. Complete sets of the prints are on file in the office of the National

Geographic Society in Washington and in that of the Director of the expeditions at Columbus, Ohio. The negatives, for the present, are filed in the Columbus office.

*No. 1.* Temperature 220° C. (Corrected). 111, N 49 E (Mag.) XXX, S 8 E. IX, N 79 E.

Approaching the Valley from the northern extremity of the Great Mud Flow, the first conspicuous fumarole was encountered about 200 yards north of the narrow neck at the easterly bend of the mud flow. The hole was about 18 inches in diameter, on a fissure perhaps 100 feet long, running east and west. The surface of the fissure was light

*Photograph by Jasper D. Sayre*

THE STEAM FROM FUMAROLE 3.

Fumarole 3 is located near the high mud mark under Station XI. The areas around it are very much broken up, and highly colored. This photograph shows the steaming fissure and its surrounding area.

colored, while the throat had a hard brown incrustation. The gases were emitted with considerable pressure, and were not condensed until several feet from the vent. This region was visited July 13th, and again on August 1st. No change could be observed; 220° C. was registered both at the surface and five feet down in the throat. Photograph 3769.

*No. 2.* T. 205° C. Needle Peak, N 51 W. 112, N 16 E. IX, N 76 E.

This was a small dry hole in the mud flow, where it had turned around the north end of Buttress Mountain and dammed Windy Lake. It was about 100 yards from the River Lethe Canyon, and just north of some sand knolls. The ground was strewn with partly charred logs and was very dry and sandy. The hole was about one foot in diameter and three feet deep, with a diagonal crevice two inches in diameter at the

bottom from which the gases were given forth with considerable force, emitting a hissing sound. Wood would char and matches ignite when left in the vent. No deposits incrusted the throat, and the gases appeared entirely free from water vapor, although there was a melting snowdrift within 50 yards of the vent. Because of this absence of steam, Fumarole No. 2 would be passed unnoticed at a distance of 100 yards. On July 14th, at the surface of the ground there was no definite temperature, it fluctuated with the wind, etc, but four feet down the temperature was 182° C., six feet down, 205° C. On July 20th, four feet down, the pyrometer registered 182° C. Photographs 4133, 4544, 4545.

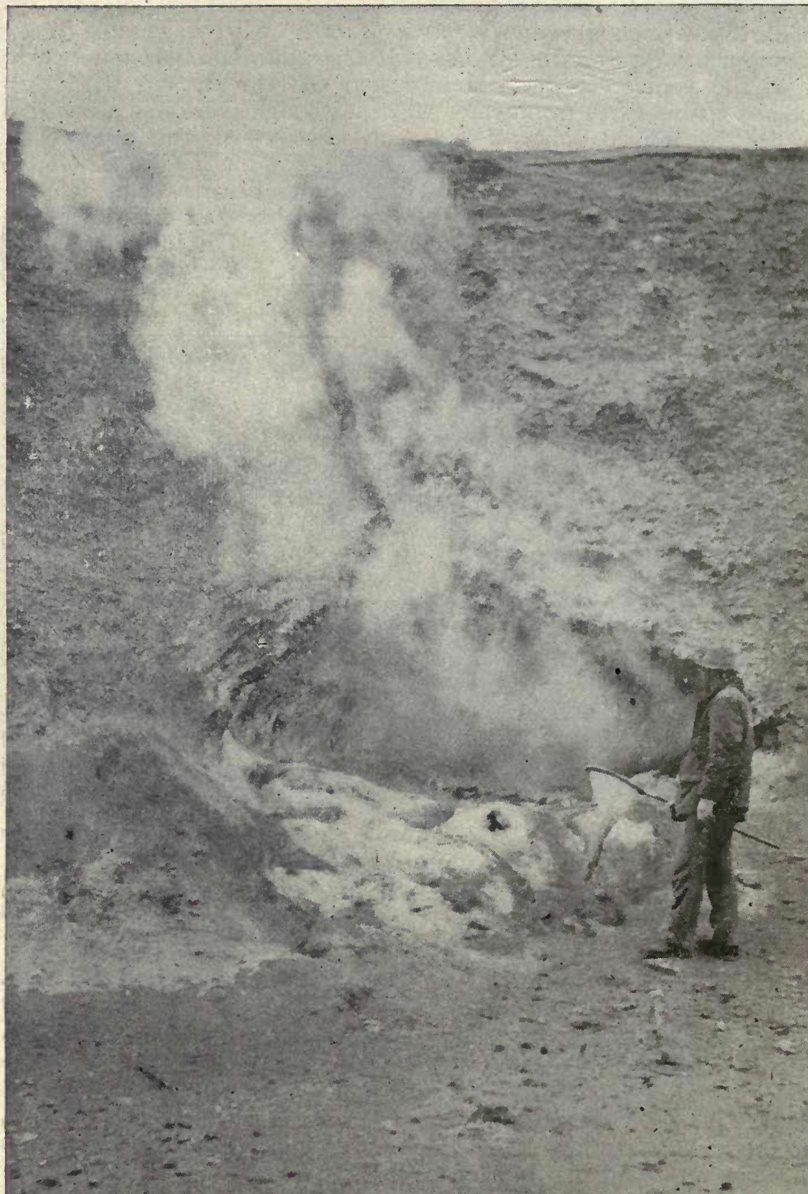
*Photograph by Jasper D. Sayre*

THE THROAT OF FUMAROLE 3.

This was the hole from which we obtained the temperature. There were several small and insignificant steaming cracks which registered only 100° C., not shown in this picture, and the mud was steaming in many places. T. 186° C.

*No. 3.* T. 186° C. 86, S 7 W. Baked Mountain, N 27 E. Mt. Cerberus, N 66 E.

This was a conspicuous steamer, with very bright red deposits, visible from any place in the upper end of the Valley. It was high up, near the high mud mark south of Station XI, about one mile north of Mageik Glacier. The surroundings were much shattered and the vent very actively steaming. The opening leads eastward and was about two feet across, evidently being the mouth of a long narrow fissure. We attempted to tap this underground fissure about ten feet from the mouth, but although the incrusted mud was only three or four feet in thickness, yet the spade would not penetrate it, as the heat had baked it as hard as rock. The opening was irregular. By placing the thermocouple from the pyrometer down in the fissure as far as we could without getting the cold junction in contact with steam, only 146° C. was recorded. At the surface, however, it was 186° C. Photographs 4521, 4522, 3697, 3698 (See cut above), 3699, 3700 (See page 262).



*Photograph by Lucius G. Folsom*

A GENERAL VIEW OF FUMAROLE 4 AS IT APPEARED IN 1917.
The shape of the throat had changed somewhat when visited again in 1918.

*No. 4.* T. 235° C. 86, S 31 W. Mt. Cerberus, S 15 W.

This was a brilliantly colored hole between Katmai Pass and Broken Mountain. The hole was on the north side of a gully, about four feet up, and was nearly two feet across, but became very small three or four feet in. The deposits were yellow and red, and very attractive. The entire gully was much visited in 1917 by Dr. Shipley. As at Fumarole 3, we attempted to tap the fissure which ran almost parallel with the surface, but were unable to break through the hard incrustation with which the tube was surrounded. The temperature at the mouth was 235° C, and about six feet down, 215° C. Photographs 3008 (See page 264), 3705.

*Photograph by Jasper D. Sayre*

THE THROAT OF FUMAROLE 6.

This irregular throat prevented us from getting a temperature very far below the surface, because it was impossible to bend the end of the thermocouple which was insulated with porcelain tubes. This picture shows the thermocouple in the position where it registered 260° C. Some indications of the bright incrustations are also shown.

*No. 5.* T. 309° C. Baked Mountain, N 19 W. XI, S 60 W. Mt. Cerberus, S 14 E.

This was a round hole about a foot in diameter in the flat surface of the mud flow north of Fumarole 4, and could be recognized by the fact that the steam did not condense until ten feet above the ground. The incrustations were light yellow and dark brown, and very hard. The temperature at the surface was 309° C; six feet down, only 231° C. Photographs 3706 (See page 257), 3707, 3708.

*No. 6.* T. 264° C. Knife Peak, N 3 W. IX N 61 W.

This acid fumarole lay in the gulch that is prominent as a notch on the upper edge of the crater rim of Novarupta. It is about 200 yards east of the edge of the crater. The deposits were a bright yellow and the

fumes very acid, of powdery white appearance, with little steam. A single breath of these fumes made one cough and run for pure air. The opening was small, irregular and cracked, but the volume of gases emitted was great. The temperature at the surface was 260° C, 1½ feet down, 264° C. Photographs 3716, 3717.

*No. 7.* T. 166° C. West of No. 6, 200 yards.

This fumarole was 200 yards N. W. of No. 6, on top of the east bank of the north-south gulch cutting across the mountain east of the crater of Novarupta. The temperature was 166° C. Some very interesting colloidal red and orange deposits were found in the throat. It was a long fissure roofed over most of the way with deposits, but steaming in several places. The best deposits were exposed by the spade about one foot down.

*Photograph by Jasper D. Sayre*

TAKING THE SURFACE TEMPERATURE OF FUMAROLE 10.

As in the case of most of the hot ones, the steam did not condense until some distance from the orifice. With the thermocouple in the position shown, the temperature was 240° C. An idea of the appearance of this vent from a distance may be gained from the Smokes in the background.

*No. 8.* T. 294° C. Mt. Cerberus, due S. Baked Mountain, N 18 W. XI, S 65 W.

This was on the Valley floor between Falling Mountain and Broken Mountain, about 500 yards beyond a big steamer under Falling Mountain, in which no temperature above 100° C. could be found although Sayre went down twenty feet into its throat supported by a rope. No. 8 was a round hole, about two feet in diameter, in hard baked sand on the bank of a gully. The deposits for 25 feet around were white and very hard, with purplish brown incrustations in the throats of the many cracks and crevices from which the hot gases were issuing. Surface temperature 294° C.

*No. 9.* T. 274° C. 500 yards southwest of No. 8.

This steamer was similar to No. 5, with no conspicuous deposits, and was 274° C. at the surface, while the highest we could find three feet down was 240° C.

*No. 10.* T. 240° C. XI, S 71 W. Baked Mountain, N 12 E.

This fumarole was 800 yards straight down the Valley from Camp V. The gully starting at Camp V would lead almost to it. We could tell that it was a hot one, because the steam came out with force, and did not condense until it was a foot or more away from the hole. The temperature at the surface was 240° C. Photograph 3720 (See page 266).

To the west of it was an area of steamers which looked hot but did not register over 100° C.

*No. 11.* T. 196° C. Mt. Cerberus, S 60 E. IX, S 81 W.

This vent was toward Fissure Lake from No. 10, and was about the last one of the line which cuts across the Valley about one-fourth of a mile from the base of Mt. Cerberus. The deposits were brilliant red and orange. The opening was large and the volume of gas great. The temperature at the surface was 196° C., three feet down it was 171° C. and six feet down, 191° C. Photographs 4536 (See page 268), 4537, 4538.

*No. 12.* T. 299° C. Baked Mountain, N 30 E. Mt. Cerberus, S 60 E. 86, S 30 W.

This area lay about 300 yards northwest of No. 11. It was a mass of small fissures with white and brown incrustations. The temperatures recorded were: 171° C., 299° C., 289° C., 250° C., 240° C., 254° C., 230° C., 171° C. The cracks are irregular, with but little steam, and it was impossible to force the thermocouple more than six or eight inches below the surface. Photographs 3721, 4539 (See page 269).

*No. 13.* T. 181° C. XI, S 55 W. Mt. Cerberus, S 50 E. Baked Mountain, N 25 E.

This was a lone fumarole without much steam, and lay north of No. 12. The temperature, both at the surface and two feet down was the same, 181° C. Photograph 3722.

*No. 14.* T. 406° C. XI, S 67 W. Mt. Cerberus, S 52 E.

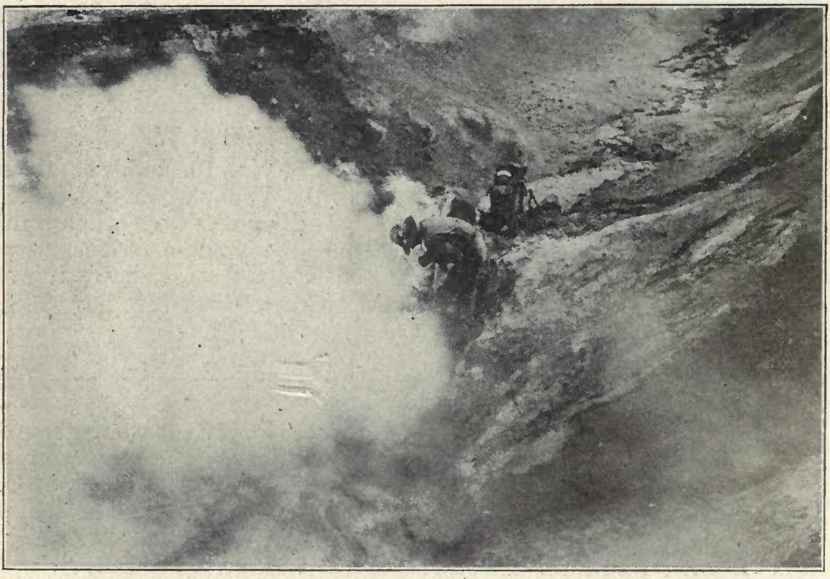
This was a long row of small craters, extending about 500 yards in a line between Katmai Pass and Station IX. The fumes from these holes were very acid, similar to those of No. 6 on Baked Mountain. The craters were conical in shape. The fumes came not from the bottoms of them, but from very small cracks in the sides or on the rim. We worked here for several hours and recorded the following temperatures from different cracks: 299° C., 323° C., 367° C., 272° C., 397° C., 392° C., 406° C., 196° C., 196° C., 323° C., 196° C., 196° C. The deposits were light colored and brown. Photographs 3722 (See page 271), 3723, 3724, 3725, 4540.

*No. 15.* T. 216° C. 500 feet west of No. 14.

This fumarole was on the same general line of craters as No. 14. The appearance also was much the same.

*No. 16.* T. 147° C. 200 feet north of No. 15.

This one was on the same general line of activity as Nos. 14 and 15, but it was a steamer. The gases were very wet, and the temperature was only 147° C. The bright orange and red deposits were conspicuous.



*Photograph by Paul R. Hagelbarger*

FUMAROLE 11.

Temperature 196° C. at the surface; 171° C. three feet down; 191° C. six feet down.

*No. 17.* T. 196° C. 100 feet west of No. 16.

This fumarole was on the same line of activity as Nos. 14, 15 and 16. It was also a steamer, similar to No. 16. The instrument recorded only 196° C. at the surface of the ground.

*No. 18.* T. 264° C. 150 feet northwest of No. 17.

This fumarole was on the same lines as Nos. 14, 15, 16 and 17. It was a small theater of hot small holes, with characteristic brown baked surface crust. We recorded two temperatures from it; one 264° C. and the other 250° C. The vents were merely small irregular cracks, neither depressed nor elevated above the general level of the Valley floor.

*No. 19.* T. 304° C. XI, S 50 W. Mt. Cerberus, S 55 E. Baked Mountain, N 48 E.

This was a big hole in the level Valley floor which gives forth steam and gases. The steam did not condense until some distance above the opening. There were no conspicuous deposits around the throat of the fumarole. It was a gray ash color similar to the surrounding Valley floor. Several feet down in the throat one could see the ordinary tuff of the mud flow. We obtained a temperature of 304° C. at the surface. Photograph 3726.

*Photograph by Paul R. Hagelbarger*

AREA 12.

This cracked and broken area, with white and brown incrustations, showed many different temperatures in the numerous crevices; maximum 299° C.

*No. 20.* T. 269° C. 75 yards south of No. 19.

Like the preceding, this fumarole was an irregular opening in the mud flow, with no conspicuous deposits, but surrounded by the common ash of the Valley floor. The temperature at the mouth was 245° C, but four feet down it was 269° C. Photographs 3727, 3728.

*No. 21.* T. 196° C. Mt. Cerberus, S 60 E. XI, S 48 W. Baked Mountain, N 48 E.

This large crater near the River Lethe was very brilliant and steaming copiously. We were unable to secure the temperature of the crater itself, but took the temperature of a small fissure in its rim. This registered 196° C. at the surface. The crater had a striking, dark red and black coating in its throat, and was a spectacle whenever the steam

cleared from its rim. This rim was nearly 100 feet across and elevated 20 feet above the Valley floor. The funnel was 50 feet to its narrow throat. The gases tested were being emitted from lateral cracks in the rim, which were only a couple of inches wide. Photographs 2316A (See page 259), 3729, 3730, 4542.

*No. 22.* T. 343° C. XI, S 54 W. Mt. Cerberus, S 25 E. Baked Mountain, N 26 E.

This was a conspicuous steamer near the high mud mark on the west side of Baked Mountain, north of the "Twins," (No. 46 and No. 47). The hole was about eight feet in diameter, and the opening within so wide that one could see plainly through the transparent superheated vapors for 50 feet or more into the cavern, which extended diagonally toward the head of the Valley.

Although a few wisps of steam begin to condense around the mouth, the main column did not condense until it had reached a distance of 20 feet from the hole. On account of its size we were not able to work satisfactorily with this fumarole, but had to be content with hanging the thermocouple over the windward side of the hole, where we found a temperature of 343° C. Photograph 4543 (See page 273).

*No. 23.* T. 352° C. Mt. Cerberus, S 53 E. Baked Mountain, S 88 E. XI, N 24 W.

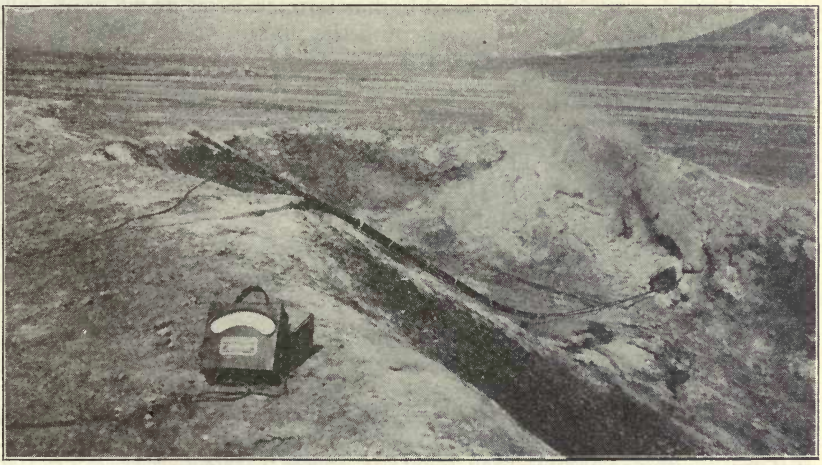
This steamer was located on the side of Buttress Mountain, near the bend in the range. It was an irregular opening with cracks radiating in every direction. We attempted to find the hottest place by sticking the thermocouple down about three feet in these different vents. We recorded temperatures in this manner of 196° C., 220° C., 245° C., and finally in one crack 294° C. This gradual rise in temperature excited our curiosity and we tried to find even higher ones. We finally recorded 352° C. as the highest temperature. This was found by holding the thermocouple suspended in the mouth of the fumarole. We repeated our observation and found that as soon as we moved the thermocouple from this certain spot it cooled off. Any other place down in the hole showed a much lower temperature. Three feet down, directly beneath the hot spot, the temperature was only 245° C. We repeated this work because we had expected to find higher temperatures down farther in the fumaroles. The deposits were heavy, bright red, orange and yellow.

*No. 24.* T. 230° C. IX, N 68 E. 111, N. 38 E. Needle Peak, N 59 W.

This fumarole had two openings, about eight inches in diameter and two feet apart. Both were 230° C. It was located in the canyon cut into the mud flow by "Chocolate Harry," the stream from under Knife Peak, near its junction with the River Lethe and Buttress Creek. The vapors were largely invisible gases rather than steam. In fact, we located it more by the noise it made than by its steam. The throats were baked hard, but the surrounding ash was soft, without conspicuous deposits. Photographs 4138, 4139.

*No. 25.* T. 274° C. X, S 59 E. IX, N 67 E. Needle Peak, N 64 E.

This was on the line of sand fissures that extends across the north end of the Valley from Pasture Peak to Station IX. It may be taken as typical of many similar fumaroles which are gradually increasing in size because wind-blown sand continually lodges around their throats. At first caught by the moisture of the steam, this is later cemented together by the emanations from the fumarole, forming showy layers of many hues. The insides of the throats are hard baked yellow. Round about were spots covered with a thin green layer of algæ (?). Photograph 3739.



*Photograph by Jasper D. Sayre*

ONE OF THE ORIFICES IN THE LINE CALLED, COLLECTIVELY, "AREA 14."

The temperature in the throat of this particular hole was 299° C. Another nearby registered 406° C.

*No. 26.* T. 196° C. 500 yards N 68 E from No. 25.

Similar to No. 25 in appearance and construction, being built up of wind blown ash, caught by the steam. Its hard baked throat was quite alone and not surrounded by any smaller cracks or crevices. The temperature was 196° C. Photographs 2141, 4140.

*No. 27.* T. 100° C. 50 yards East of No. 26.

Although similar to Nos. 25 and 26 in appearance and apparently as hot, this fumarole was much cooler and gave off much more steam than either one of the foregoing. It was not until we unpacked our pyrometer that we found that its temperature was only 100° C., otherwise we would not have stopped here. There was no conspicuous color in the throat, but the steam bathed ash was covered with a greenish crust. Collections of this ash are being cultured for algæ and moss protonema.

*No. 28.* T. 216° C. X, S 55 E. IX, N 67 E.

This was a long line of steamers, one hole of which showed a temperature of 216° C. Others registered 196° C. and 161° C. The main vents were 100 feet apart, closely similar in appearance. They were surrounded by numerous steaming cracks which stood at 100° C.

*No. 29.* T. 329° C. IX, N. 24 E. Baked Mountain, S 60 E. 111 N 0.

This was a long line of acid fumaroles. After many trials, we secured the highest temperature, 329° C. They were richly colored small holes. The whole line was slightly raised above the general level of the Valley floor. We began at one end of the line and after recording several crevices at 100° C., found higher temperatures as we approached the middle of the line, finally reaching the maximum of 329° C. Some of the other crevices recorded 313° C., 294° C., 259° C. Toward the other end of the line the temperature fell again to the boiling point. Photographs 3740, 4141.

*No. 30.* T. 304° C. 111, N 9 E. Baked Mountain, S 62 E. IX, N 35 E.

We found here a large gasser situated on a long fissure. Many small cracks in the vicinity were emitting steam at 100° C. There were no conspicuous deposits. The temperature at the surface was 304° C. Photograph 3742.

*No. 31.* T. 210° C. Baked Mountain, S 60 E. IX, N 20 E. Needle Peak, N 71 W.

Two large columns of gas, which registered 210° C. and 205° C., were conspicuous among numerous minute hissing steam jets. The area was not conspicuously colored, being covered with wind-blown ash. Photographs 3743, 4142.

*No. 32.* T. 323° C. Baked Mountain, S 64 E. IX, N 5 E. Needle Peak, N 64 W.

The immense volume of steam issuing from this fumarole first drew our attention to this one. It was the most conspicuous vent in the lower (north) half of the mud flow. No other fumaroles were near and its large irregular mouth, which rose 15 to 20 feet above the Valley level and emitted a huge column of rolling steam and gas, made it a very striking vent. The hot active area was so large that it was impossible to do more than work around some of the outer crevices, leaving the temperature in the center of the column to conjecture. In the subordinate fissures we found temperatures of 225° C., 304° C., 220° C., 304° C., 323° C. and 294° C. See page 274.

*No. 33.* T. 432° C. Baked Mountain, S 62 E. IX, N 15 E. Needle Peak, N 62 W.

The main body of the stream flowing from the Valley under Knife Peak cuts across the area of No. 33. An enormous quantity of rolling steam and vapors, which had attracted our attention from the first,

came from this area. On arriving, we found the whole area on both banks of the creek steaming. Most of the orifices were minute, but after a search of several minutes, we found one large enough to receive the thermocouple, where we found a temperature of 432° C., the highest we observed anywhere in the Valley. The deposits were very hard white material, but the throats were invariably purplish brown, with occasional small masses of deposit resembling blue or green glass. Other crevices round about gave temperatures of 392° C. and 382° C. Photographs 3744, 3745, 4144, 4145 (See page 276).

*Photograph by Paul R. Hagelbarger*

FUMAROLE 22.

This fumarole was about eight feet in diameter. The main column of steam did not condense until twenty feet from the opening. With the thermocouple hung over the windward side of the hole, as in the picture, we obtained a temperature of 343° C.

*No. 34.* T. 159° C. 111, N 14 E. IX, N 34 E. Baked Mountain, S 66 E.

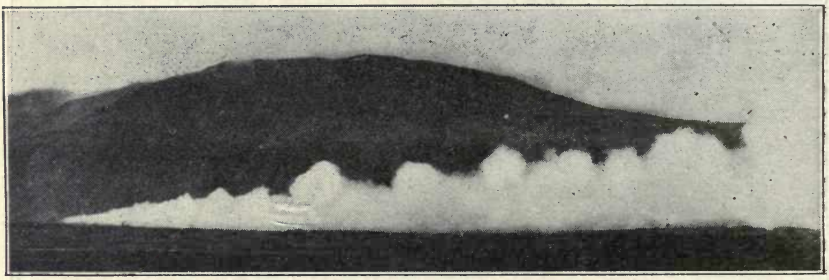
Between Fumarole 33 and Camp VIII we followed the easterly bank of the River Lethe Canyon and recorded a temperature of 159° C. in one of the many steam masses so conspicuous along this stream. We stopped at a number of openings that gave a temperature of only 100° C. We noticed no conspicuous deposits in this vicinity because the area was covered with a thin layer of wind-blown ash.

*No. 35.* T. 245° C. 111, N 20 E. X, S 60 E. XXX, S 20 W.

This steamer was on the bank of the River Lethe, and was similar to No. 34 in appearance, except that the temperature was higher. The mouth of the fumarole was about 12 to 14 inches in diameter and surrounded by hard baked mud, without deposits. Surface temperature 245° C.

*No. 36.* T. 245° C. IX, N 22 W. Mt. Mageik, S 26 W. X, S 51 W.

This fumarole was on the east bank of the canyon formed by the stream flowing out of the Knife Peak Valley, and marked the upper end of the impassable mud canyon which this stream forms. The main vents were surrounded by quite an area of steaming ground. The deposits were red and yellow, around the larger and hotter vents. Temperatures of 245° C., 171° C., 181° C. were recorded. Photograph 4552.



*Photograph by Robert F. Griggs*

FUMAROLE 32 FROM A DISTANCE.

The man silhouetted against the steam near the vent gives the scale. Although the outlying cracks accessible to our thermocouple registered only 323° C., this place has every appearance of being hotter than No. 33, where the highest temperature measured in the Valley was found.

*No. 37.* T. 342° C. 100 yards east of No. 36.

This fissure was nearly overlooked, as it appeared no hotter than No. 36. However our inquisitiveness was rewarded in discovering that it had a surface temperature of 342° C. The mud here had a crack 100 yards long and the temperatures at various places along this crack were 284° C., 294° C., 314° C. and 342° C. The deposits were yellow and brown near the mouth of the vents while a few feet away from the line of the fissure the ground was ordinary gray ash.

*No. 38.* T. 100° C. IX, N 39 W. X, S 82 W. XI, S 3 W.

This mass of steam from a distance suggested a temperature of 300° C. at least, but although we tried every crack and crevice in an area of an acre or more, at no place did we succeed in securing a temperature above 100° C. The ground here was covered with a grayish, bluish-black mud about eight inches deep that remained nearly 100° C. in temperature and very disagreeable to work ankle deep in. This marked the northern limit of these mud blanketed areas. Photographs 3753, 3755, 4148, 4150.

*No. 39.* T. 122° C. X, S 65 W. Mt. Mageik, S 20 E.

A single isolated fumarole caught our attention and, as it seemed so far away from the Valley proper and so close under Knife Peak, we thought that the extra time required to go to it would be rewarded with a high temperature. We certainly were disappointed, however, when the finger of the pyrometer stopped at 122° C. Soft wind-blown ash and pumice surrounded this fumarole. The throat was brownish in color and not very hard in texture. Photographs 3757, 3758.

*No. 40.* T. 191° C. X, S 38 W. Mt. Cerberus, S 37 E.

This was the first vent on a line of steamers and gassers that lay south of Station IX, near the edge of the mud flow. The ridge that marks the fissure line is broken in many places by the formation of eruptive craters. Several crevices showed only 100° C., but two were hotter, being 191° C. and 112° C. The throats of these two were red, but not otherwise conspicuously colored.

*No. 41.* T. 254° C. 500 yards south of No. 40.

We were drawn to this region by the copious steaming of No. 40, but, failing to find a high temperature in its steam, were about to pass on when the steam from No. 41 caught our eye. It did not condense for three or four feet from the mouth of the vent, so we knew it must be hot. There were brown and white deposits in and around the throat of the fumarole. The temperature recorded was 254° C. at the mouth of the vent. Photograph 4150.

*No. 42.* T. 221° C. X, S 26 W. Mt. Mageik, S 26 E. Needle Peak, N 75 W.

This line of craters was close to No. 41. In No. 42 three craters lay in a line, about 20 feet apart, but only the middle one was accessible, as the others were too deep and funnel shaped. This one registered 221° C. and had a dark red and orange throat about one foot in diameter. The crater, which was about three feet deep, had a rim of about 50 feet in circumference. The throat was in one side of the bottom of the crater.

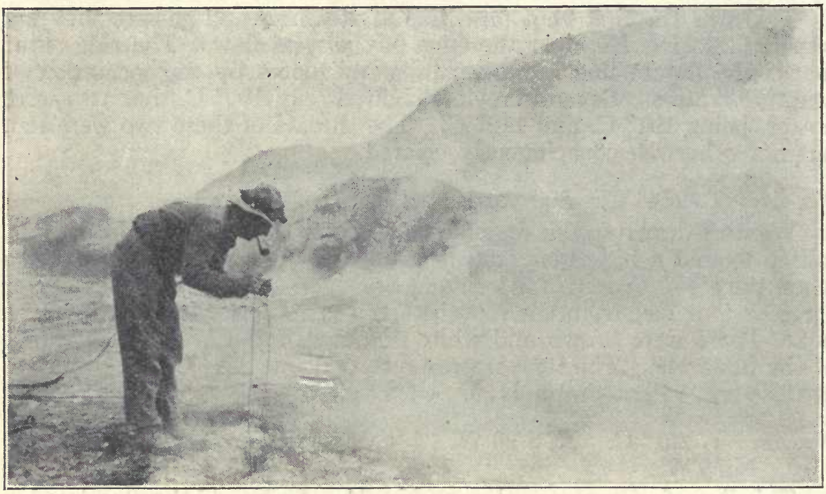
*No. 43.* T. 100° C. Mt. Mageik, S 28 E. X, S 29 W.

Although registering only 100° C., this fumarole, at the vanishing point of a small creek, was located because of its conspicuousness. The steam rushed forth with great pressure and roared from many cracks in the vicinity, indicating perhaps a higher temperature below the surface. No deposits were noticed, probably being covered up by the shifting ash and sand.

*No. 44.* T. 100° C. Mud Volcanoes, first area. IX, N 13 W. Mt. Mageik, S 31 E. X, S 23 W.

From a distance this appeared as a gentle area of steamers. It was not until we had approached the center of the area, waist deep in steam, blown close to the ground by the wind, that we realized it was different.

Globules of blue mud shot into the air with a pop and fell back into its basin with a splash, only to be followed by many similar outbreaks all around us. Going to windward we saw the seat of the trouble. The ground was covered with boiling blue mud pots, some with a consistency of well cooked mush, while in others the boiling water was almost clear. It was impossible to secure satisfactory pictures of the performance, because of the thick blanket of rising steam that covered an area of an acre or more. The mud was blue black. The temperature was that of steam, 100° C. Photographs 4146, 4151, 4152, 4558, 4560.



*Photograph by Paul R. Hagelbarger*

PLACING THE THERMOCOUPLE IN FUMAROLE 33.

This inconspicuous crack, with the thermocouple placed as in the picture, gave a temperature of 432° C., the highest measured in the valley. The ground near the fissure was too hot to stand on very long, so we supported the cold junction of the thermocouple on a spade.

*No. 45.* T. 412° C. IX, N 10 W. X, S 19 W. Mt. Mageik, S 35 E.

Between No. 33 and No. 36 and the east bank of the canyon from Knife Peak Valley was a conspicuous steamer. As we approached it, 200 yards to the eastward, we came upon the end of the fissure which gave forth a big column of steam where it was crossed by the Canyon. The deposits here were light colored. At different places in the small cracks in the roof of the fissure the temperatures were 289° C., 318° C., 387° C., 412° C., 402° C., 397° C. The main steamer, we found, had a temperature of 360° C. at the surface of the ground.

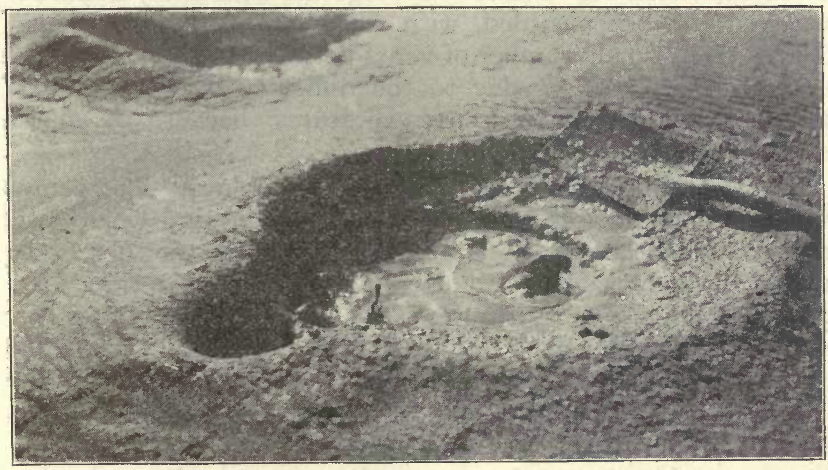
*No. 46.* T. 171° C. 500 yards south of No. 22.

This fumarole was on the same line of activity as No. 22, and was very similar to No. 22 and No. 47. It was a large circular hole in the roof of a wide fissure probably caused by a cave in. There was an

immense volume of steam coming from it. In the pictures, this and the next appear as one opening. The temperature recorded from it was 171° C. This was obtained by hanging the thermocouple over the edge of the cavity, and does not in our opinion correctly represent the temperature. It was, however, the only place accessible with the wind in the southeast, as it was when we visited it.

*No. 47.* T. 309° C. 50 feet south of No. 46.

This fumarole was on the same line of activity and similar to No. 46, except perhaps that the opening was larger and emitted a greater volume of steam. This one was easier to work with because the wind was favorable. With the thermocouple bent and hung eight feet over the edge of the hole, the temperature was 309° C.



*Photograph by Jasper D. Sayre*

A MUD POT IN AREA 48.

Boiling mud may be seen spattering up from the bottom, left and right.

*No. 48.* T. 100° C. Mud Volcanoes, second area. Mt. Cerberus, S 48 E. Baked Mountain, S 84 E. 86, S 3 W. X, N 63 W.

This was a nest of mud pots, boiling and sometimes spouting three feet into the air. A crater ring of considerable size had been formed around some of them. The mud was a chocolate brown, and no conspicuous deposits or incrustations were noticed. All had a temperature of 100° C. Photograph 3693 (See cut above).

## SUMMARY AND DISCUSSION OF RESULTS.

1. The highest temperature measured was 432° C. This, (No. 33), was found in a small and relatively inconspicuous crack which one would have expected to be cooler than great volcanoes like No. 32, in which the center of the steam column was inaccessible to our instruments.

2. We measured 102 vents with temperatures above 100° C. in the 48 areas which we visited and located. Nine vents with temperatures between 390° and 440° C. were measured; 28 vents between 290° and 390° C.; 49 vents between 190° and 290° C.; 16 vents between 100° and 190° C.; together with many hundred measured but not recorded, with steam at the boiling point. The relatively small number of vents between 100° and 190° C. is to be interpreted as due to the difficulty of working the thermocouple between these temperatures, because of short circuiting by condensing steam.

3. The temperatures of a number of chimney-like vents were distinctly highest at the surface of the ground where the hot gases met the air. The greatest difference was observed in No. 23, which was 107° C. hotter at the surface than three feet down the hole, the temperatures being—surface, 352° C.; three feet down, 245° C. Such differences were observed in Nos. 3, 4, 5, 9, 11 and 23.

This increase of temperature at the surface is interesting in view of the fact that the opposite was expected. (a) Since the gas presumably issues from a molten magma beneath the surface, one would expect a steady lowering of the temperature gradient from the hot magma to the cold air. (b) Since the gas issues under considerable pressure, roaring and hissing as it rushes out of the orifice, its expansion if carried out adiobatically would considerably lower the temperature.

While it would be easy to hypothecate reactions of gases that would liberate heat enough to produce the observed rise in temperature, such a speculation could have little value until the gases can be examined chemically. The analyses now under way and projected by the Geophysical Laboratory of the Carnegie Institution ought to throw much light on this question.

SCIENTIFIC RESULTS OF THE KATMAI EXPEDITIONS OF THE NATIONAL GEOGRAPHIC SOCIETY.

# IX. THE BEGINNINGS OF REVEGETATION IN KATMAI VALLEY.

Robert F. Griggs.

The effect of the great eruption of Mount Katmai in Alaska on plant life, and the remarkable recovery of vegetation around Kodiak have been discussed in previous papers of this series.[1] When it was observed with what rapidity the covering of ash at Kodiak was being removed by erosion, and that the new plant covering consisted almost entirely of old plants which had survived and come up through the ash, it became evident that the main problem of revegetation must be worked out on the mainland, where the destruction of the antecedent vegetation was more complete, and the deposits through which new plants must start very much deeper.

The present paper is published as a record of the first stages of this process in the valley of Katmai River, which, flowing from the Volcano in a narrow canyon, empties out and for some twenty miles traverses a broad flat valley to the sea. (See map, page 319). These flats, in contrast to the steep mountains round about, contain considerable areas favorable to the study of revegetation.

## METHODS OF WORK.

A considerable part of the work of the expeditions which visited the country in 1915, 1916 and 1917, was the securing of records, both descriptive and photographic, of definite localities which may be visited at later dates and re-studied for the purpose of recording the progress of returning vegetation.

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[1] Griggs, R. F., Scientific Results of the Katmai Expeditions of the National Geographic Society.

I. The Recovery of Vegetation at Kodiak. Ohio Journal of Science 19: 1-57. 1918.

IV. The Character of the Eruption as Indicated by Its Effect on Nearby Vegetation. Ohio Journal of Science, 19: 173-209. 1919.

A full citation of literature is given in these papers, especially in I. General accounts of the expeditions have appeared in the National Geographic Magazine for January, 1917, and for February, 1918.

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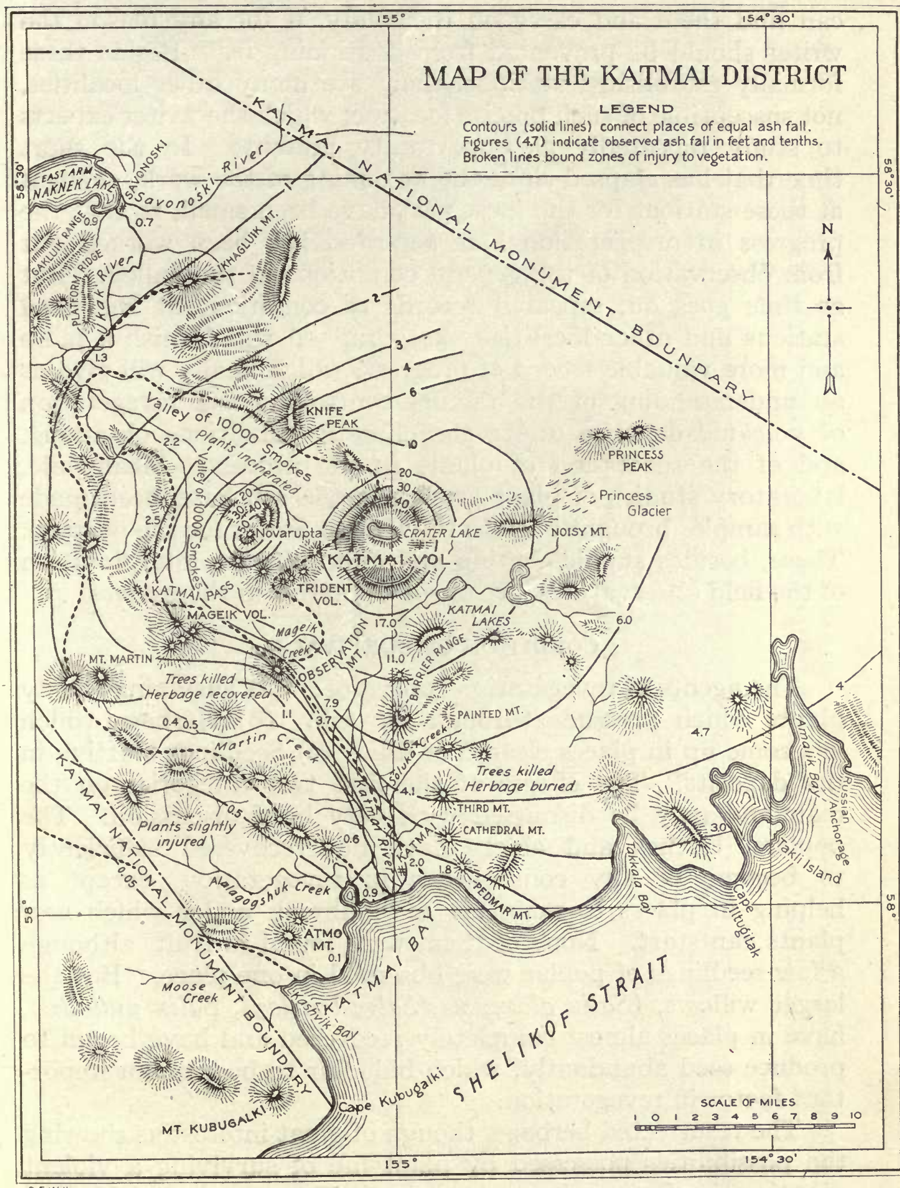

MAP OF THE KATMAI DISTRICT
LEGEND
Contours (solid lines) connect places of equal ash fall.
Figures (4.7) indicate observed ash fall in feet and tenths.
Broken lines bound zones of injury to vegetation.
KATMAI NATIONAL MONUMENT BOUNDARY
Valley of 10000 Smokes
Plants incinerated
Novarupta
KATMAI VOL.
CRATER LAKE
KNIFE PEAK
PRINCESS PEAK
Princess Glacier
NOISY MT.
TRIDENT VOL.
KATMAI PASS
MAGEIK VOL.
MT. MARTIN
Trees killed
Herbage recovered
Trees killed
Herbage buried
Plants slightly injured
KATMAI LAKES
BARRIER RANGE
OBSERVATION MT.
PAINTED MT.
THIRD MT.
CATHEDRAL MT.
PEDMAR MT.
ATMO MT.
KATMAI BAY
SHELIKOF STRAIT
MT. KUBUGALKI
Cape Kubugalki
Kashvik Bay
Moose Creek
Alalagogshuk Creek
Martin Creek
Katmai River
Soluka Creek
Takkala Bay
Cape Ilugitak
Amalik Bay
Russian Anchorage
Takli Island
EAST ARM NAKNEK LAKE
Savonoski River
SAVONOSKI
GAKLUIK RANGE
PLATFORM RIDGE
Kak River
KHAGLUIK MT.
SCALE OF MILES
155°
154° 30'
58° 30'
58°
O.E. Williams

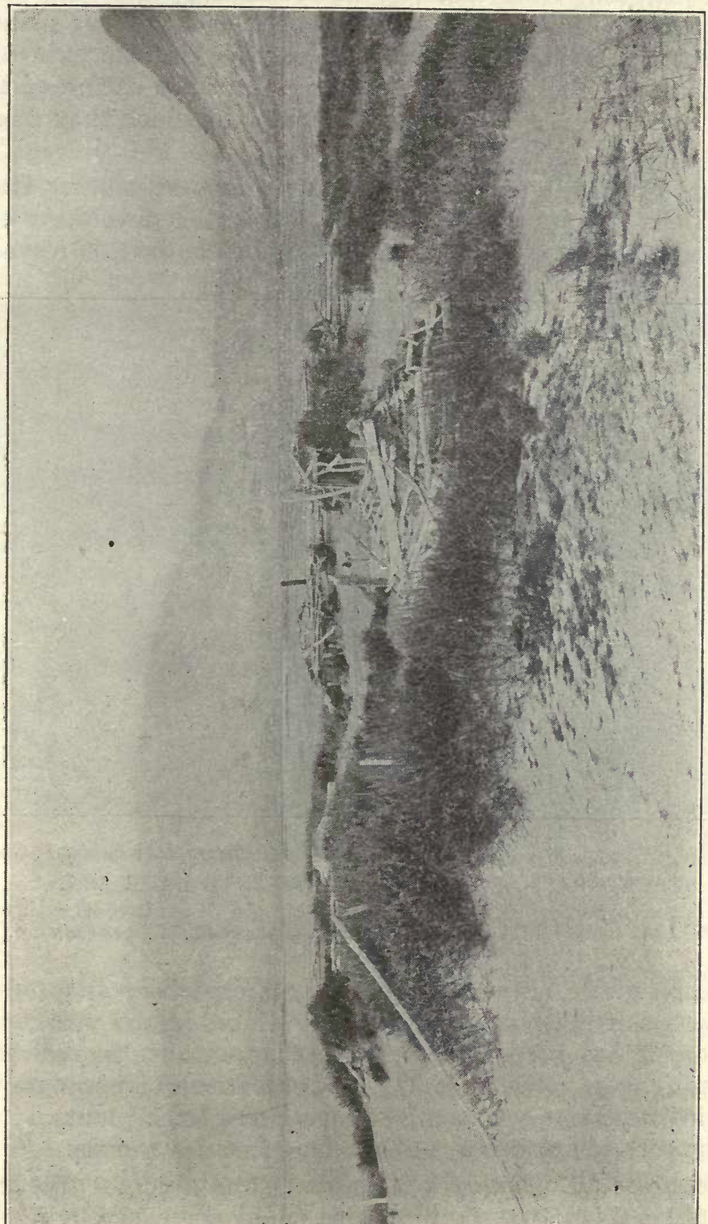
The effort has been to locate them in such a way that anyone can find them and carry on the study, if for any reason the writer should be prevented from continuing it.* Beside these formally established stations, there are many other localities, not susceptible of such precise location, which the writer expects to study repeatedly as opportunity presents. In the short time that has elapsed since the beginning of the work, changes at these stations for the most part have been small, so that the progress in revegetation here reported has been worked out from observation of the general conditions in the valley. But as time goes on, repeated records of conditions at the fixed stations and other localities photographed will furnish a more and more valuable record of progress, which finally will give us an understanding of the factors controlling the revegetation of volcanic deposits under the climatic conditions obtaining, and of the succession of plants in the process. Meanwhile, laboratory studies of plant growth in the ash have been made with samples brought back to the United States for the purpose. These, besides supplementing and aiding in the interpretation of the field observations, are of some interest in themselves.

## CONDITION OF SURVIVALS.

The agents of revegetation consist of: (a) Surviving woody plants which protrude through the ash. (b) Herbage which has come up in places cleared of ash. (c) Seedlings starting in the deposits. The effects of the first two categories on the mainland may be dismissed with very brief discussion. The poplars, birches and alders have not recovered sufficiently to become of any consequence in revegetation, except as helping in places to maintain a windbreak under which new plants can start. None of them were found in fruit, although a few seedlings of poplar were observed in one place. But the larger willows, (*Salix alaxensis*, *Salix barclayi*, *Salix nuttallii*), have in places almost completely recovered and have begun to produce seed abundantly, which bids fair to become an important factor in revegetation.

The resurrected herbage, though of great interest as showing the possibilities possessed by plant life of surviving a violent eruption, is of minor importance in the revegetation of Katmai

*For a detailed discussion of the problems encountered in establishing the vegetation stations see the first paper of this series, pp. 24–31.



*Photograph by D. B. Church*

A PORTION OF KATMAI VILLAGE FOUR YEARS AFTER THE ERUPTION.
The increase in the vegetation is exclusively by vegetative extension. The present rate is about four feet per annum.

Valley. Although the oases, to be found in spots where conditions have permitted the recovery of the herbaceous plants, are conspicuous in the desert valley, their influence in the revegetation of the great bare areas is, from the nature of the case, quite limited. There are three ways in which they affect revegetation.

First, by direct extension out into the bare areas. Only two of the species present have sufficiently developed the power of sending out runners to be important in this respect.

*Photograph by Robert F. Griggs*

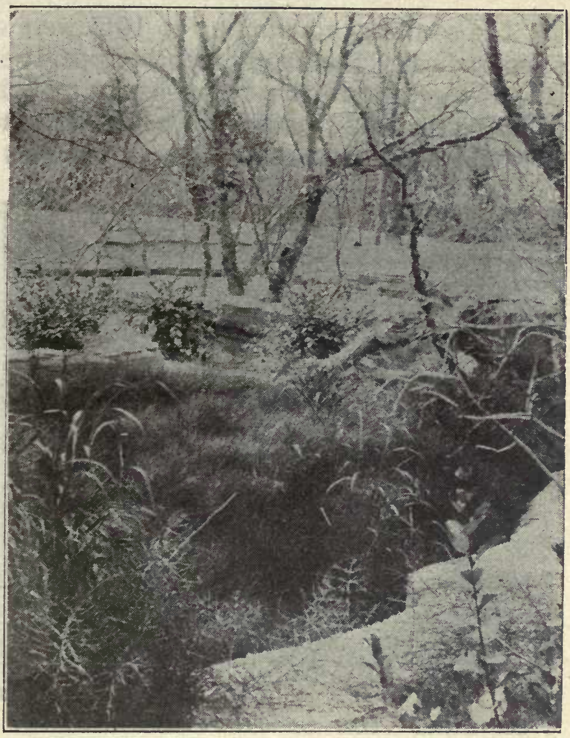
BEACH GRASS SENDING RUNNERS INTO BARE ASH.

Runners of the current season (1916) are sterile, but the shoots that came through in 1915 have fruited. The rate of extension is about four feet per annum.

The beach grass, (*Elymus arenarius*), is especially adapted to cope with shifting sand, and in many places in the vicinity of the shore it has been locally of great importance in renewing the plant cover. (See page 321.) Comparison of photographs taken in successive years and observation of the plants shows that the rate of extension is about four feet per annum.

The horsetail, (*Equisetum arvense*), was able to penetrate deposits so thick that nothing else could come through. Its capacity for penetration is most strikingly shown in the bottoms

of numerous gullies washed in the ash areas where it was so deep that nothing could come through on the level. Observation of such places shows that it can penetrate deposits up to about three feet in thickness. The horsetail is not, however, of anything like the importance in Katmai Valley that it is at Kodiak.* The deposits are for the most part so thick that it is only here and there that even the horse tail could grow through them. (See picture.).



*Photograph by Robert F. Griggs*

EQUISETUM COMING THROUGH IN THE BOTTOM OF A GULLEY WHERE THE DEPOSIT WAS TOO THICK FOR IT TO PENETRATE ELSEWHERE.

Second, the patches of surviving herbage serve as a wind break in the shelter of which new seedlings can start. This again is a function of considerable importance locally as will be seen from the discussion to follow.

Third, the oases of resurrected vegetation furnish the seed which may be the basis for starting new vegetation in the desert round about. This, however, is not a factor of great consequence in this case. The plants have come back on the steep mountains, from which the ash quickly slid off, so much more freely than in the deeply buried valley that they would furnish abundant seed, even if nothing had survived on the flats. Most of the plants of the district have seed adapted

*See the first paper of this series, p. 43.

for wind distribution, and the wind is so efficient a factor in this region, (see page 339), that seed in abundance is transported great distances.

### SEEDLINGS BEGINNING TO START.

The seedlings starting up to 1915 were so few, and occurred so sporadically, that in my report of operations that year I stated that revegetation had not yet begun and that the observations of that year could furnish no basis for a prediction as to when it would begin, but a definite change was noticeable in 1916.

*Photograph by Robert F. Griggs*

A GENERAL VIEW OF THE PUMICE PLAIN ON WHICH LUPINES WERE STARTING.

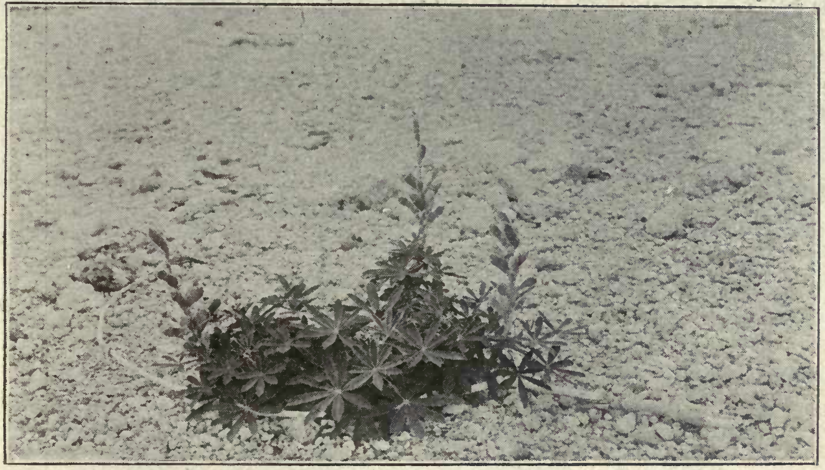
The dark spots right and left are lupines, like that shown close up on the opposite page. Although far apart they have grown thriftily.

The landscape was, to be sure, as bare as ever, but the careful observer could not fail to see in many habitats the definite, though slight, beginnings of new vegetation. These were most marked in the lower valley, and diminished as one approached the Volcano, but even in the upper valley large areas which were absolutely barren in 1915 were coming up with occasional lupine seedlings which, though so sparse and widely scattered that one had to search for them, were nevertheless thriving with every prospect that some of them would survive. Farther down the valley a few areas were found where similar seedlings

had started in 1915 and, having persisted even in deep pumice deposits, were flowering and seeding abundantly in 1916; while in 1917 considerable areas as far up stream as Martin Creek were sparsely occupied by fruiting lupines, furnishing the basis for an increasing rate of revegetation.

### LUPINES THE MOST EFFECTIVE PIONEERS.

While the new vegetation in the lower valley consists of many species of plants, in the more exposed places lupines are the only pioneers. (See pages 324 and 335). For this role they are well adapted, because of their large heavy seeds



*Photograph by Robert F. Griggs*

A LUPINE ON THE PUMICE FLAT AT MARTIN CREEK.

These plants first appeared in 1915. They were well provided with root tubercles and grew thriftily, fruiting freely in 1917. The soil is almost entirely without organic nitrogen.

which lodge where smaller seeds are blown away. On germination, moreover, their large supply of stored food enables them to grow into strong plants much more quickly than the other species present. But their capacity of utilizing atmospheric nitrogen through their root tubercles is probably the decisive factor, for the ash is almost devoid of nitrogenous compounds.[2] Lupines growing in pumice show an abundant development of root tubercles which must give their possessors enormous advantages over ordinary plants in the process of revegetation.

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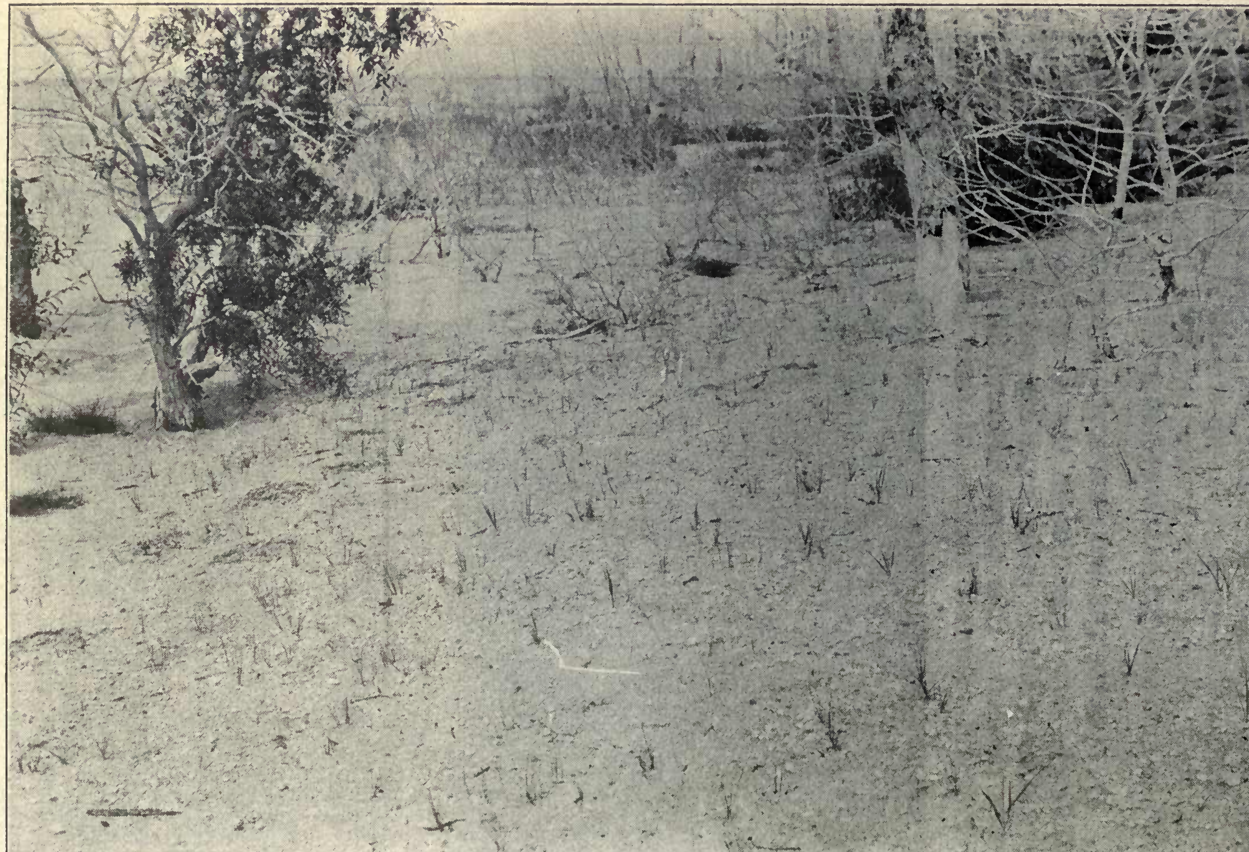
[2] Shipley, J. W. The Nitrogen Content of Katmai Ash. Paper No. V in this series, pages 213–223.



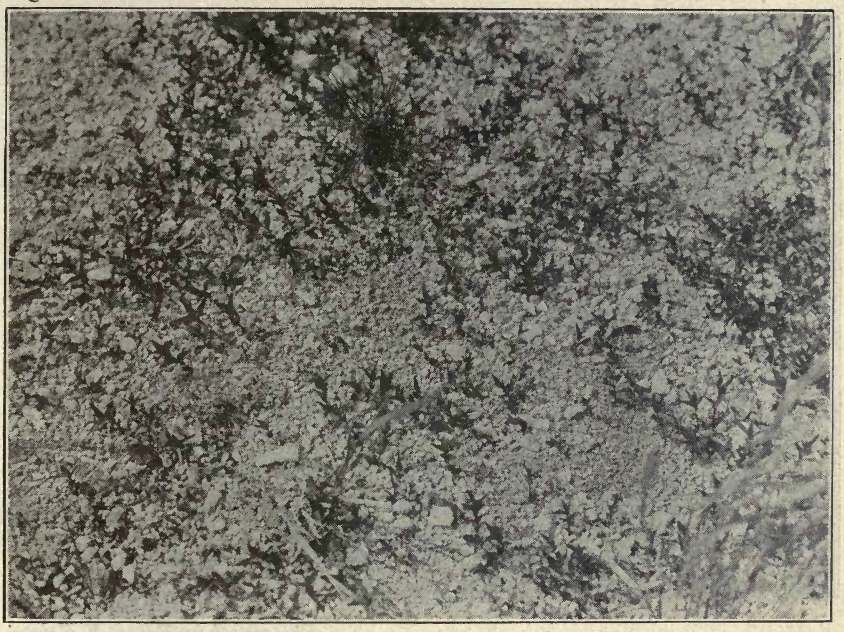
*Photograph by D. B. Church*

SEEDLINGS STARTING IN WATER-LAID ASH.

In outwash at the base of a hill where the ash was little contaminated with soil. Most of the abundant seedlings are grasses. (*Deschampsia* and *Calamagrostis*). The picture is not typical of conditions in Katmai Valley.

These lupines are, however, strictly confined to the valley and to situations that at one time or another have been overflowed by stream waters. On the surrounding hillsides and in other parts of the valley there are many areas that, to all appearance, offer quite as favorable habitats as those which are occupied by lupines, but not a single plant has ever been detected outside the flood plains except on oases of old soil.

The reason for this peculiarity of distribution is not clear at the present time. It may be that the seeds are water borne

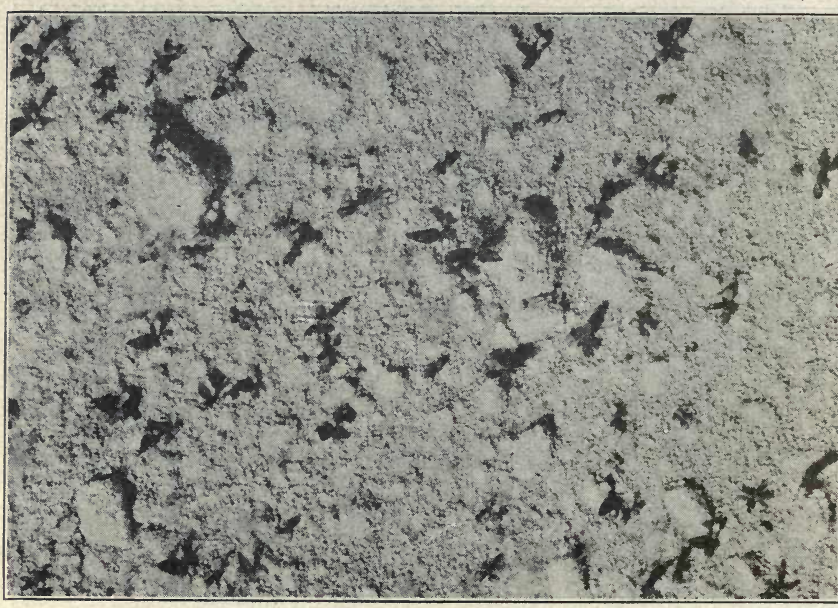


*Photograph by D. B. Church*

SEEDLINGS OF EPILOBIUM ALASKÆ STARTING ON PUMICE IN A SPRINGY PLACE.

instead of wind disseminated. But the winds of the district are so extremely violent, (see below, page 339), as to make it appear unlikely that objects so slight as lupine seeds would resist their action. Legumes in general are known to be dependent on organisms in the soil for that innoculation with the tubercle bacteria upon which their success is dependent. It might well be that while these organisms were absent from the general mass of ash they were present in ash contaminated by flood waters.

Bacterial examinations of the soil in the neighborhood of the growing lupines, conducted by Jasper D. Sayre, have however failed to indicate the presence of the tubercle bacillus in the soil. The ash is extraordinarily poor in micro-organisms. Cultures from numerous collections made in 1917 remained altogether sterile, while in others a single organism developed consistently on some media. Otherwise no micro-organisms whatever were found, although the check samples of garden soil subjected to the same treatment fairly teemed with bacteria,



*Photograph by Robert F. Griggs*

WILLOW SEEDLINGS COME UP IN FLOOD BORNE MUD IN KATMAI VALLEY. NATURAL SIZE.

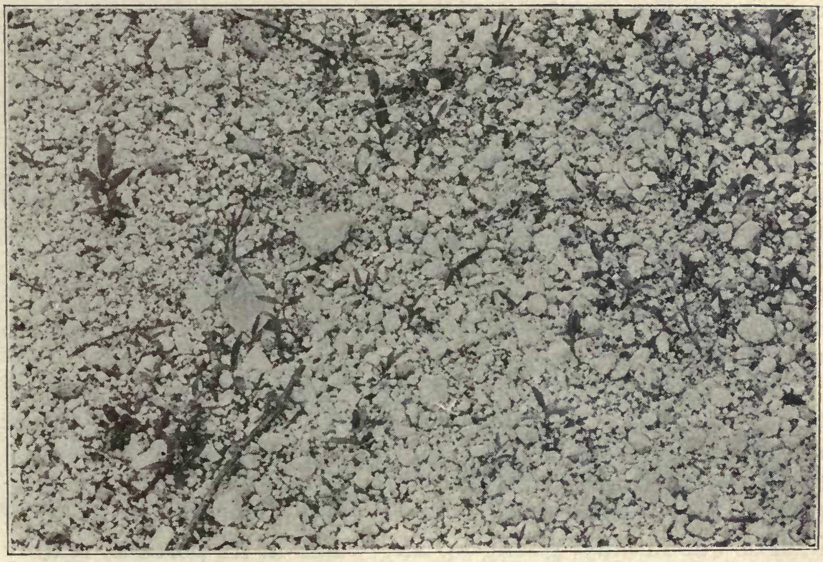
indicating that there was nothing wrong with the methods of collecting and culturing the material.

The cultural work was interrupted at this stage by conditions incident to the war, but through the kindness of Dr. K. F. Kellerman, the Department of Agriculture undertook to investigate our suspicion that the one organism so consistently found was the tubercle bacillus. But when the report came it was negative. Our organism was pronounced not to be *Bacillus radicicola*. The matter must therefore be left in

abeyance. But Mr. Sayre is continuing the bacterial work, having made further collections of soil for bacteriological study during the summer of 1918.

WILLOWS STARTING IN SOME PLACES.

In more sheltered situations, seedlings of a number of species are starting in many places. The most important of these are probably the grasses, *Deschampsia caespitosa* and *Calamagrostis langsdorfii*, (see page 326). With these are other herbaceous



*Photograph by Robert F. Griggs*

YEARLING WILLOW PLANTS GROWING IN WATER-LAID PUMICE.
The appearance of these plants in August, 1915, is shown on page 328.
This picture was taken in August, 1916.

species, including *Artemesia tilesii*, *Campe barbarea*, (see page 331), *Polemonium acutiflorum*, *Epilobium alaskæ*, (see page 327), *Mimulus langsdorfii* and also the frutescent *Sambucus pubens*. There are also considerable areas where the ground is covered with seedlings of willow, (*Salix alaxensis*, *Salix barclayi*, *Salix nuttallii* and *Salix bebbiana*). (See page 328). Many of these latter survived the first winter and made vigorous growth in 1916. They have not, perhaps, established themselves well enough to justify the prediction that the pioneer growth over

considerable areas will be a willow thicket, but present indications point in that direction. In 1915 seedlings of all sorts were scarce, though many were starting at the time of our arrival. But the following season it could be seen that, while great numbers of them had been winter killed, many had survived and were growing. Since the first winter would appear to be the most critical period in the life of seedlings, and especially since the winter of 1915-1916 was unusually severe in its effects on vegetation at Kodiak, it is to be supposed that these seedlings are the beginning of the new, permanent plant covering of the country.

### SEEDLINGS ESPECIALLY IN WET PLACES.

These new plants, especially the herbs, show certain peculiarities of distribution which throw much light on the factors retarding revegetation. Except the lupines, which are always in well drained situations, the new seedlings show an evident preference for wet places, or more correctly, for places which bear evidence of water action. For they are not confined to springy places, the edges of ponds and the like, but also appear in numbers on some of the outwash deposits which are not especially wet habitats.

The readiest explanation of this preference would be that the ash in general has insufficient moisture to meet the water requirements of the plants. This might be expected, moreover, from the fact that the ash is purely mineral and altogether lacking in humus or similar water-holding substances, so that it dries out rapidly, giving up any water in its pores as readily as sand. Under ordinary climatic conditions this would probably be an important factor, but those who are familiar with this region will agree that it is difficult to imagine anything drying up here, so constant is the rainfall.

The season of 1915, in which occurred an unprecedented drought, gave an exceptional opportunity, however, to test the importance of this factor. Even at the close of the drought the ground was everywhere visibly moist immediately beneath the surface. To ascertain more definitely the exact situation, soil moisture determinations were made in the field. These were followed by determinations of the wilting coefficient, both by the centrifugal machine through the kindness of Dr. H. L. Shantz, and by tests of pot cultures under the writer's direction.

The results of these tests showed clearly that in all sorts of habitats there was a considerable margin of available moisture, even at the close of an unprecedented drought.

PREFERENCE FOR WET PLACES POSSIBLY DUE TO CONCENTRATION OF SALTS.

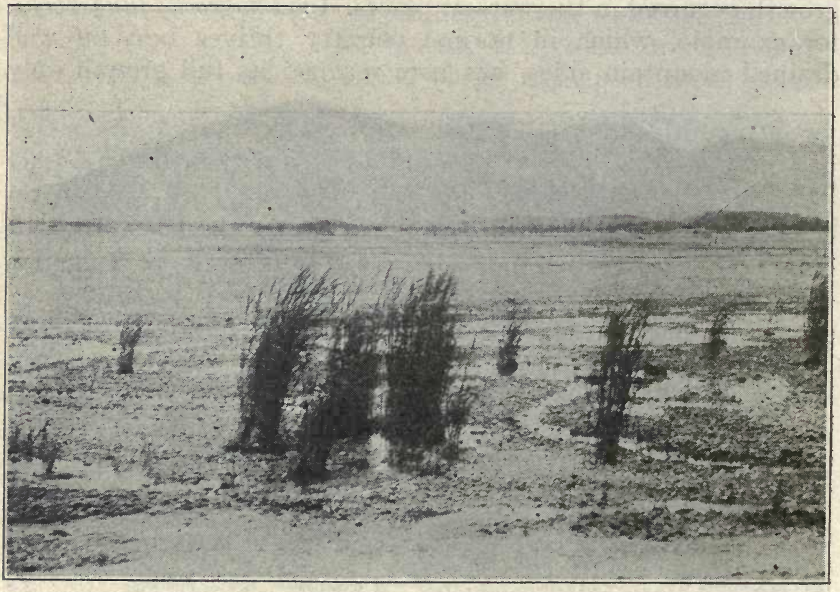
But in spite of this it could not be questioned that the rankest growth occurred in the wettest places. *Calamagrostis langsdorfii*, for example, which in normal country thrives best on well drained mountain sides, has here reached its full growth only

*Photograph by Robert F. Griggs*

SEEDLINGS, MOSTLY CAMPE BARBAREA, STARTING IN A WET PUMICE FLAT.

in springy places where the water is so abundant as to stand on the surface. (See page 332). For a long while it was very much of a puzzle why it did not spread onto the adjacent ground, whose soil-water content is more similar to that of the habitats it usually occupies. But finally an explanation suggested itself because of the similarity of conditions in these places to the alkali spots on the prairies. Everyone familiar with such a region as the Dakota prairies has noticed that such springy places become covered by a heavy crust of alkali salts, left behind from the evaporation of the seepage water. The places occupied by the plants in question present exactly

similar conditions. Evaporation from the free water surface must similarly affect the concentration of salts. The ash contains such small amounts of the soluble salts necessary for plants that it may be supposed that only where concentrated by evaporation do they occur in amounts sufficient for vigorous growth.*



*Photograph by Robert F. Griggs*

CALAMAGROSTIS LANGSDORFII APPEARING IN AN AREA WHERE WATER, COMING TO THE SURFACE, MAY HAVE ITS SALTS CONCENTRATED BY EVAPORATION.

Surrounding pumice flats, where the surface is protected from evaporation, are bare.

If this reasoning is correct, it would explain the decided advantage of the plants in the wettest places over those on the general surface of the ash where the loose top layer, acting as a

*Dr. Shipley, in the sixth paper of this series, has reported that the total soluble salt content of the ash is in general not especially low. But in analysis directed particularly toward the solution of this question, Professor C. W. Foulk, found that in the ash at Kodiak the amount of available (*i. e.*, water soluble) potash was only 0.05%, which is exactly the amount given by Hilgard as the minimum concentration requisite for plant growth. Phosphoric acid was present in an even smaller amount, which Professor Foulk described as slightly more than a trace, although it was so small that he made no attempt to give it a numerical value. The high salt content found by Shipley is probably made up, therefore, of salts not important to the growth of the plant.

mulch, prevents evaporation. It has not proved practicable as yet to submit this hypothesis to experimental test, but it has been found that it is impossible to obtain in pot cultures from small quantities of ash anything like such vigorous growth as occurs even in dry places in the field where the plants have unlimited possibilities of root extension with the consequent ability to draw upon wide areas for the necessary quantity of salts.

*Photograph by Robert F. Griggs*

SEEDS COMING UP WHERE COVERED UP BY THE OUTWASH OF A TEMPORARY STREAM.

General surface of the ash bare. Lower Katmai Valley.

### SEEDLINGS IN DRY WATER-LAID DEPOSITS.

The distribution of only a portion of the new plants can, however, be accounted for on this hypothesis. Those coming up in outwash deposits are often so situated as to be kept better drained than the surrounding level. (See cut above.) At first I was inclined to suppose that such deposits were sufficiently contaminated by admixture of the original humus soil washed off the mountains along with the ash to present quite different and altogether more favorable conditions for the

plants than the undisturbed ash deposits. But further study led me to doubt the correctness of this view, and this doubt was confirmed when it was found that pot cultures of this material were no more successful than those in which the undisturbed ash was used.

Meanwhile the field study was carried out on the hypothesis that the water content of the soil was inadequate. It was reasoned that numerous seedlings should have started in periods of wet weather, even in very unfavorable places. If this had happened many of these seedlings would have been caught in the drought and their dead and dying remains would have been easy to find. But, as a matter of fact, prolonged search failed to disclose any such, except in one solitary instance. This was considered remarkable, since, even under the conditions of the Central States, it would be easy to find numbers of seedlings which had perished in any considerable drought, even though mature plants had not suffered seriously. Moreover, since the bare ash surface is free from plant debris of any kind over considerable areas, seedlings if present could not have been overlooked. It became evident that there had never been any seedlings on the general surface.

Here, then, was another significant fact which required interpretation. The most obvious explanation would be that the ash contained some substance deleterious to the germinating seeds. In the vicinity of the crater and in certain other special localities* some such chemical is evidently present, but it is certain that no such deleterious substance is generally present. It has been shown, both by chemical analysis and by the experience at Kodiak, that there is nothing injurious to plants in the ash deposited at that distance. The pot cultures made on the return to the States showed, except in special instances, that plants do not behave differently when grown in ash from the mainland than in that from Kodiak.

It was then suspected that the reason for the barrenness of the undisturbed ash might lie in the fact that its smooth surface afforded no lodgment for seeds which, distributed largely by the terrific gales that sweep the country, are carried across the smoother surfaces and dropped in situations better adapted to catch them.

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*Dr. Shipley, in the sixth paper of this series, pages 224–229, has shown that in a few localities the ash bears so strong a concentration of ferrous sulphate as to be toxic to plants. But the occurrence of such deposits is limited to very special situations.

SEEDS PLANTED BY RUNNING WATER.

To test this hypothesis and at the same time to ascertain whether there was anything in the deposits which might prevent germination, buckwheat was sown in various habitats. At each planting the seeds were sown in two ways—by placing them in the ground and by scattering them on the surface of the ash. On our return to the Base Camp after the expedition up the valley, it was found that the seeds planted in the ground

*Photograph by Robert F. Griggs*

LUPINE SEEDLINGS SPREADING OUT INTO BARE ASH.

Under the protection of the old vegetation along a dune ridge, they have started in deep ash beyond the ridge. When mature they will widen the strip of protecting vegetation and facilitate further the spread of vegetation. Katmai beach, August, 1916.

had in every case come up well and showed normal growth, which continued as long as we stayed. But of those scattered on the surface of the ash not a single individual was found. Since the vicinity of the Base Camp abounds in birds, it was thought that perhaps the seeds scattered on the surface might all have been picked up by the birds, and we awaited with interest opportunity to examine similar plantings made at Katmai Village where there are no birds and the wind sweep

is greater. When examined, all of these with a single exception, were found in the same condition as the others—the planted seeds had all come up, while those strewn on the surface had blown away. In one of the sowings, however, though almost all had blown away, there was one small spot where a number of seeds had come up. This was found to be in a heel mark made

*Photograph by Robert F. Griggs*

A BEAR TRAIL THAT SPROUTED.

The depressions in the tracks of the heavy animal caught wind-borne seeds, which drifted across the smooth surface round about without finding any place of lodgment.

by someone who had walked across the area and pressed a few seeds down into the soil with his foot! For nearly two weeks after these seeds were planted, moreover, there had been no hard blows, but considerable rain and mist, so that they may be said to have had as favorable an opportunity for catching hold as could have been given them under the climatic conditions of the region.

The same conditions are held responsible for the fringe of seedlings found along the outwash deposited by temporary streams. (See page 333). Seeds buried in the outwash

*Photograph by Jasper D. Sayre*

THE SAME BEAR TRAIL A YEAR LATER.

From a somewhat different position. The grasses in the track have made notable growth, but no new plants have started in the general surface of the ash, although the horsetail in the background, probably a survival, has considerably extended its runners.

deposits were protected from the wind and given favorable conditions for germination in situations where none had caught hold on the ground surface of the ash. Similar conditions, but less striking, were found at Kodiak. (See the first paper of this series, page 51).

In 1917 further striking natural demonstration of the inability of seeds to lodge in the general surface of the ash was supplied by the discovery of several bear trails that had "sprouted." The depressions made by the animal's tracks in the soft mud had served to arrest numerous wind blown

seeds which otherwise would have drifted clear across the barren flats without finding any lodgment. The seeds thus caught had sprouted and grown well, proving that in that particular place, at least, the principal deterrent to revegetation was the inability of seeds to catch hold. When examined a year later, the plants growing up in the tracks had made a notable growth, as may be seen by comparing pictures taken in the two years. (See pages 336 and 337).

### WIND EROSION A GREAT DETERRENT TO REVEGETATION.

But the effect of the wind on vegetation is not to be measured merely by its influence as a seed disseminator. Much more important is its effect on the soil itself. It is so violent that it keeps the surface of the ground over large areas always in an unstable shifting condition, so that plants have little opportunity to start.

The wind is, indeed, one of the most important factors retarding the revegetation of the devastated district. In another place I have shown how important it is in the vicinity of Kodiak.* Near the Volcano the total devastation and the conformation of Katmai Valley give it a clear sweep so as to greatly intensify its effects and augment its importance.

Here the snowdrifts which accumulate during the winter are buried under a mantle of wind blown sand which is often more than half a meter thick. Our observations on such drifts in 1916 showed uniformly that the sand had all accumulated after the snow fell, for it lay as a sharply distinct layer on top of the snow and the two were not interbedded. This indicates that it was all accumulated during a short period in the spring. (See page 339). Such sand-blanketed snow is very slow in melting and in places shows little wastage even as late as the first of August, which of itself is a factor of considerable moment in retarding the renewal of vegetation on the snow covered areas.

The abrasive power of this shifting sand, as it is carried by the wind, is very considerable. There are large tracts in the upper valley in which the sandblast has cut away the bark and even abraded the wood on the northwest side of the dead trees, leaving them uninjured on the lee side. A forest of such trees is most striking testimony of what the wind can do.

*The first paper of this series, pages 37-39.

### KATMAI A VERY WINDY COUNTRY.

Unfortunately the weather records taken by the Government do not include measurements of wind velocity, so that there are no data for giving exact statements concerning the winds. The best that one can do therefore is to report some

*Photograph by Robert F. Griggs*

A SNOWDRIFT BLANKETED BY ASH.

The insulating power of the ash is indicated by the fact that the snow beneath did not melt for five years. Wind-blown ash so retards the melting of the snow throughout the heavily covered country as to lower the altitude of the line of permanent snow fields.

of the effects of wind action, in order to enable the reader to form some conception of its violence. In this region the regular westerly gales approach in velocity the tornadoes which occasionally sweep our middle western states. Spurr[3] states that the natives cannot be induced to cross Katmai Pass except in fine weather, because the wind picks up stones and carries them with such force as to have killed many men. In Kodiak, a heavy dory was once picked up from the beach and carried up hill for a hundred yards, finally smashing in the front of a house before it stopped. Winds of only less violence are of common occurrence.

At our camp in the upper valley we have measured, with a weather bureau standard anemometer, winds blowing steadily 60 miles per hour, and much higher in the gusts. But the camp was in an especially sheltered situation, chosen especially with reference to avoiding such winds. Up on the mountains it was much worse, for there it picked up pieces of sharp pumice up to an inch in diameter and carried them with such force as to inflict painful blows where they struck one's flesh. Pieces even twice as large, though too heavy to be carried aloft, went scurrying over the slopes almost like dry leaves before the gale.

## REVEGETATION GREATLY RETARDED BY SHIFTING STREAMS.

Another factor retarding vegetation, whose importance is almost as great as that of the wind, is introduced by shifting water currents. The streams were completely choked with ash and pumice by the eruption, and have not yet recovered from that condition. They are so overloaded with detritus that they have built up fans and flood plains many feet above the former levels of their beds. Over these great deposits of loose material they wander helplessly in many shifting channels, now here, now there, now cutting away, now building up. It is evident that no plants can obtain a foothold in such places until the streams settle down enough to give them a chance at the soil.

[3] 20th Ann. Rept. U. S. G. S., pt. 7., p. 91.

## FICKLE CREEK SHIFTS ITS COURSE ONE THOUSAND FEET IN A YEAR.

Perhaps the most astonishing instance of the instability of the country was encountered when we traveled up toward Soluka Creek in 1916. Here, as elsewhere, the country looked perfectly familiar, but when we tried to find our last year's camp our memories seemed to fail us, for we could not locate it. How we could have missed it was a mystery, for it was conveniently located on the bank of a tumultuous torrent which supplied us with water. Curious to check up our unusual lapse of memory, we hunted and hunted through the dead forest in search of the old camp.

Finally we found the tent pins and the coals of the fire, just as we had left them, but the creek was nowhere in the vicinity. It had moved a thousand feet away.

Not only was the stream gone, its very bed was missing as well. The year before it had flowed in a steep sided trench, six feet below the general level, but now the ground was all smoothed off so perfectly that we could not detect the position of the former bank after the most careful search.

That some plants can start in such places, when the surface remains undisturbed, was shown by an examination of the area beyond the migrations of the stream. In 1915 this was absolutely sterile, but the next year we found in a space of about ten acres one seedling of Carex, two of *Calamagrostis langsdorfii*, two of another grass, a solitary specimen of *Chamaenerium augustifolium* and one patch of moss. Such feeble beginnings of plant life may strike the reader, familiar only with regions of luxuriant vegetation, as altogether too insignificant to deserve notice. But such is not the case, for these scattered plants, few and humble as they were, demonstrated the possibility of new plants starting in deep and pure ash deposits. Whether they were able to survive or not is questionable, but even if they succumbed they attained a size and weight far in excess of the seeds from which they originated, and their decaying bodies will furnish material for other plants to carry along the revegetation—that is, if the stream does not shift and wash them out.

## HUMUS FORMATION THE REAL PROBLEM.

To the field worker the instability of the ground produced by the operation of these factors appears so important as to overshadow all else in the problem of revegetation. But experience with areas of high wind and loose soils outside the Katmai district clearly indicates that the shifting sands would be quickly caught and stabilized by the advancing vegetation if it were not for the lack of sufficient "plant food" in the ash. If such plants as start were able to grow thriftily, it would be only a relatively short time until the whole valley was again covered with luxuriant vegetation.

The real problem of revegetation is, therefore, the *nitrogen supply*. When the ash was thrown out from the Volcano in a fused condition, it was of course completely free of organic nitrogen. Dr. Shipley's work, reported in the fifth paper of this series, page 213, shows that the ash soil still remains extraordinarily poor in nitrogen compounds.

The task before us is, therefore, to follow the process by which a supply of combined nitrogen is built up in these soils as vegetation gradually returns, supplementing field observations on the plants with chemical and bacteriological examinations of the substratum. If this process of humification can be followed successfully, the knowledge so obtained will throw much light on many problems concerning the relations of plants to the soil, of great importance from both a theoretical and a practical point of view.

SCIENTIFIC RESULTS OF THE KATMAI EXPEDITION OF THE NATIONAL GEOGRAPHIC SOCIETY.

## X. BIRDS OF THE KATMAI REGION.*

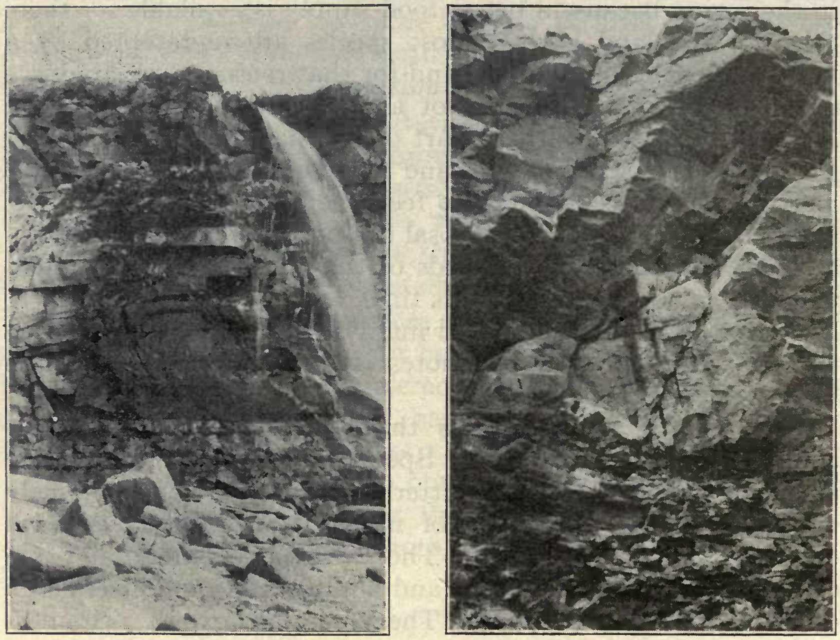
JAMES S. HINE.

Most of the birds taken by the expedition were procured near the mouth of the Katmai River. Water birds predominate in the region because a better food supply is available for them than for the land birds. Most species are represented by a large number of individuals, and for that reason there are large numbers of birds although not a great many different kinds. Kashvik Bay, the southern part of Katmai Bay, is the feeding grounds of thousands of gulls and related forms and an immense amount of food is required to feed them.

Since the time at my disposal did not allow the making of a complete collection of the birds of the Katmai district a complete list is not possible at this time, and since it is the plan to list only the species taken and many of the characteristic birds are not represented a few notes on the commoner Alaskan birds precede the others.

One of the noisiest birds the summer through was the common loon of the region. Specimens were seen commonly and often passed overhead uttering their hoarse and homely notes giving the suggestion of nearness to a farmyard with domestic ducks in full song. The red-breasted Merganser is a common species in the region and adults with young were seen on more than one occasion. The young are expert swimmers and are very difficult to capture, even when only a few days from the egg. The species was very quiet about its haunts at all times and was observed only when we came upon it without its knowing of our approach. During the last days of August many well organized flocks of geese and swans passed over our camp. The bald eagle was seen at various times. This was one of the few birds observed flying over the Valley of ten thousand Smokes. It was not flying high but apparently was not inclined to linger over and was soon out of sight in more productive territory. The raven is widely distributed in Alaska and one is

nearly sure to hear their notes wherever he happens to be. Several pairs nested on the rock shelves of the sea wall near our base camp. The young were able to leave the nest during the first part of July. Snowflakes were often seen on the tops of peaks, and in Katmai Canyon members of our party found them on several occasions. Along the upper course of Mageik Creek we saw a pair of these birds and heard them sing. We had been on the trail for hours without seeing either animals or



Two views of the sea wall along Katmai Bay. View at left shows nesting site of the Glaucous winged Gull; at right, of Pelagic Cormorant.

plants; suddenly in the distance we heard the song of the male snowflake and as we proceeded on our way the song became clearer. Finally we came to an immense spring of clear water which it seems had been the means of preserving a few bunches of grass at its outlet and the pair of snowflakes had found them. These bunches of grass were the only green plants we had seen for miles and their presence associated with the singing bird and its mate gave a feeling of pleasure which was very much appreciated.

**Fratercula corniculata** (Naum.). Horned Puffin.

A species often observed. Nests were located in crevices of the rocks of the sea wall. Hundreds of pairs were seen and when walking along the beach below the sea wall when the tide was low one could see specimens every few feet flying from their nesting sites. Specimens appeared to use crevices in the rocks as security from storms and natural enemies or as places in which to rest as well as for nesting places.

**Cephus columba** Pal. Pigeon Guillemot.

Common. Nests in the crevices of rocks like the puffins. Often seen in flocks of a half dozen or more resting on the surface of the water. A series of specimens shows variations from those very much mottled with white all over to black with a large white spot on each wing. They utter a shrill whistle when frightened and resent being approached too closely.

**Rissa tridactyla pollicaris** Ridgw. Pacific Kittiwake.

We did not see these birds at Katmai until about the tenth of August when they appeared in large flocks. At times they composed a large percentage of the gulls present in Kashvik Bay. Flocks of hundreds were seen together commonly.

**Larus glaucescens** Naum. Glaucus-winged Gull.

This very large gull was common on the Katmai coast during our whole stay in the region. They nested all along the sea where the rock wall was present. Soon after our arrival they began nesting and before we came away the young had grown to full size and were about with the old ones. The adults are very noisy birds, especially in the vicinity of their nests. Ravens, foxes and other animals are their enemies and keep them in a state of uproar most of the time. Their notes often become a source of annoyance for so long as one remains near the shore he is never out of the sound of their voices. Many nests were located and it was found that they lay from two to three eggs, usually on shelves of almost inaccessible rocks but at times on top of the cliffs where they can be reached easily from above. The young remain among the rock crevices and run under cover when they realize they are observed. We constructed an improvised ladder to use in studying the nests, eggs and young, and were able to see many of them. Often when the young

could not find a crevice large enough to hide their whole bodies they would be satisfied with hiding their heads and covering their eyes. They grew rapidly and their homes became very foul smelling abodes for the parents appeared to keep them well supplied with an abundance of food which consisted mainly of the common brittle shelled clam, Siliqua patula Dixon, and often when I climbed to their nests I found their runways strewn with numbers of partially eaten representatives of this species in different stages of decomposition.

*Photo by J. D. Sayre*

Nest and Eggs of Glaucous Winged Gull.

**Larus canus brachyrhynchus** Rich. Short-billed Gull.

Numbers of this species were among the thousands of specimens of gulls to be seen about Kashvik Bay during the latter half of August. A specimen in immature plumage was taken August 23d.

**Larus philadelphia** (Ord.). Bonaparte Gull.

About the first of August large flocks of this gull appeared about the rich feeding grounds of Kashvik Bay. Several specimens were taken on the second of August.

**Phalacracorax pelagicus** Pallas. Pelagic Cormorant.

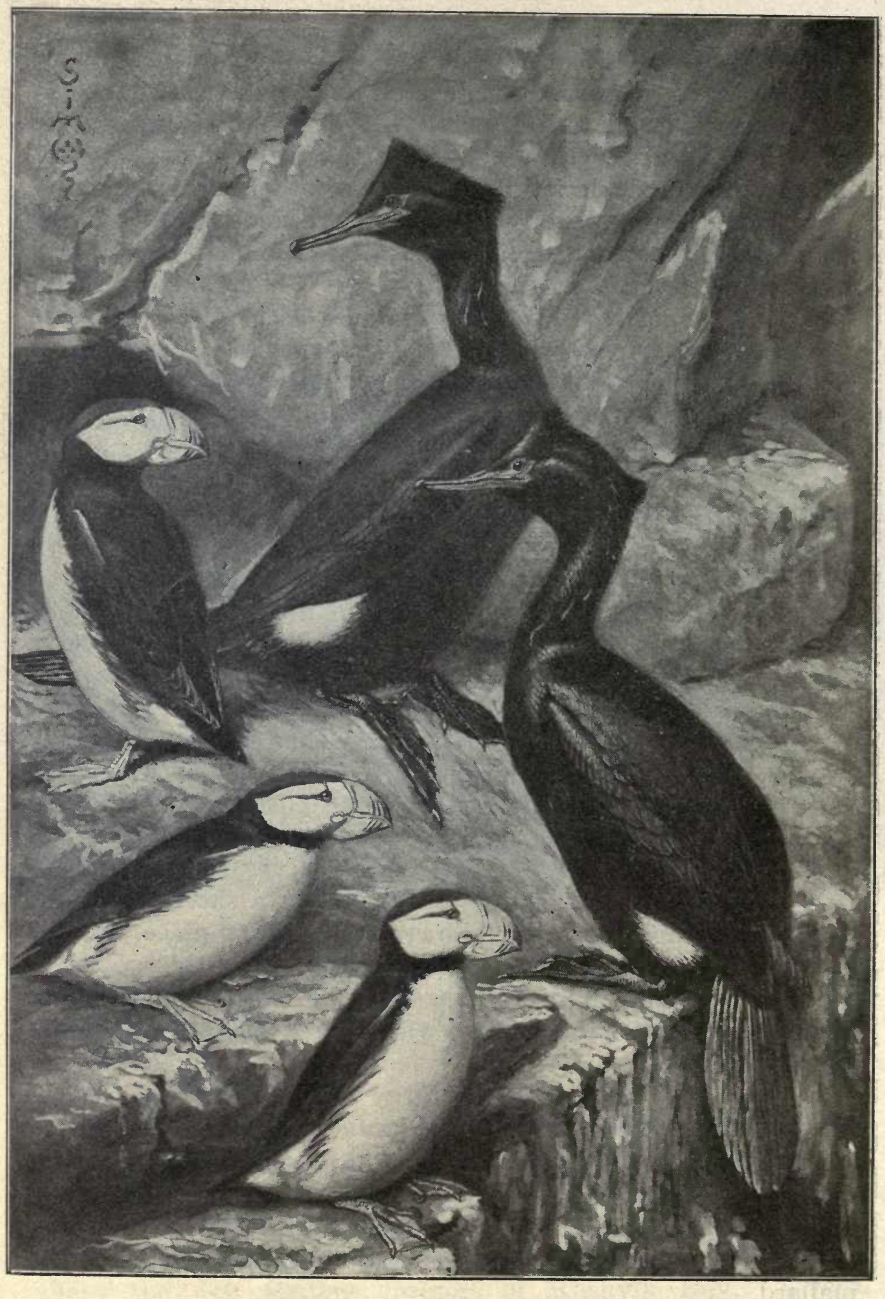
Colonies of this cormorant nested on the shelves of the sea wall along Katmai and Kashvik Bays. Several nests were investigated and several sets of eggs taken. The eggs do not differ in any particulars from the eggs of other cormorants and a set is three or four usually. The nests are composed of slender grasses tightly packed together and matted so as to form a firm mass closely applied to the rock shelves which support them. The adults cling to their nests rather closely although some specimens are more easily flushed than others. These nests become rather repulsive before the young leave them for they remain in them for a long time and feed upon fish with which they are rather bountifully supplied by their parents.

**Anas platyrhynchus** Linnæus. Mallard.

The mallard is common in Alaska, especially in the fresh water lakes which abound in many places. These lakes often occur only a short distance back from the sea and many of them are exactly suitable for mallards. Adults and their young were seen frequently in June and the grown up young ones were seen and taken plentifully in August. There is no greater sport from the standpoint of the bird student than to come suddenly upon a brood of young mallards. The manner in which the mother manages the situation and the ease with which the young as well as the old one disappear from view are matters of interest from the standpoint of the observer. Usually, it is fairly easy to procure one of the young for a short study if a specimen is singled out and followed to its hiding place, but one need not be altogether discouraged if every one of the specimens succeed in eluding him, and there is left only the excitement of the very brief confusion into which the ducks are thrown by the surprise.

**Mareca americana** (Gmelin). Baldpate.

The American widgeon, as some of our hunters call it, was seen occasionally and specimens were procured from small bodies of fresh water near the mouth of Katmai River. The species does not appear to be as common in the region as the mallard.



Pelagic Cormorant at right; Horned Puffin at left.

**Clangula islandica** (Gmelin). Barrow Golden-eye.

Taken August 20, from a small lake. Observed at other times during the summer. From information gathered it is a rather common species in the region.

**Histrionicus histrionicus** (Linnaeus). Harlequin Duck.

The species was always taken in immature plumage and is one of the commonest species of the region. Flocks were frequently observed swimming in open sea water or sunning themselves in quiet coves along the shore. The people of Alaska call them Kommandants and they are supposed to be very hard to shoot. They easily dive when shot at but dive in time and returning to the surface within a few feet quite rapidly move out of range.

**Somateria spectabilis** (Linnaeus). King Eider.

Hundreds of ducks were seen far out in Katmai Bay on different occasions apparently feeding as is suggested in systematic fishing. It was not possible always to be sure of the species of ducks observed but we were reasonably sure that more than one was thus engaged at one time. Specimens of the King Eider were taken near the mouth of the Katmai River, June 28. There is very good reason for believing that other eiders and some of the scoters, at least, take part in the systematic fishing operations of the region; but as none but the King Eider was taken, the statement has to be based upon field observations which are not altogether trustworthy because the birds were seldom close enough for accurate identification.

**Phalaropus lobatus** (Linnaeus). Northern Phalarope.

Seen in small flocks swimming in pools adjacent to the mouth of Katmai River, July 25, and specimens taken. Flocks were seen on different occasions over a period of three or four weeks. They are very quiet birds, only uttering peeping sounds which may be heard only when one is near them. They never showed a great deal of fear, allowing one to approach within a few feet before taking wing. They swim easily and make an attractive appearance in the water.

**Arquatella maritima couesi** Ridgway. Aleutian Sandpiper.

Several specimens of this bird were seen along the sea shore among the stones. Three specimens were taken August 20 to 22. Only two or three specimens were seen at any one time.

**Clangula islandica** (Gmelin). Barrow Golden-eye.

Taken August 20, from a small lake. Observed at other times during the summer. From information gathered it is a rather common species in the region.

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**Somateria spectabilis** (Linnæus). King Eider.

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**Pissobia minutilla** (Vieillot) Least Sandpiper.

A few specimens were observed on the beach near the mouth of Katmai River and one specimen was taken July 23.

**Pelidna alpina pacifica** Coues. Red-breasted Sandpiper.

One specimen taken August 23, on a sandy beach near the mouth of Katmai River. I did not find it in numbers at any time.

**Ereunetes mauri** Cabinis. Western Sandpiper.

Large flocks were common on sandy stretches of beach for several days. Taken July 23 and August 2, and observed frequently for a longer period.

**Glottis melanoleuca** (Gmelin). Greater Yellow-legs.

This species nests commonly along the coast of Katmai Bay and several pairs were seen. It is very noisy in the vicinity of its nest and young. Some pairs found something to scream about most of the time night and day. When some of our party were not passing their way it seemed that some animal or other was bothering. We often wondered when they found time to eat, and feed and care for their young. Their notes may be heard plainly for a half mile or more and during the time they think they are being imposed upon at their nesting grounds, they spend part of the time on the ground and part perched on the tips of the taller trees in the vicinity, and as they appear very nervous and change from one to the other often much time is consumed on the wing and the antics they perform in the air are difficult to describe. It was sport to tease them when we could do it as well as not without wasting valuable time for that purpose alone, but the birds proved to be so much more persistent than we were and seemed never to tire of screaming and performing air antics that we usually retired from the conflict and left the birds screaming long after we were thoroughly tired of their noise and more than willing to forget it.

**Heteroscelis incanus** (Gmelin). Wandering Tattler.

A pair of these birds was observed along a rocky coast on Katmai Bay, August 3. They took wing several yards ahead of us and alighted again further on, repeating the procedure several times and making their characteristic sounds every time they took wing, finally going far out over the water and drop-

ping back behind us. One specimen was procured August 3, and another August 25, the latter a bird of the season with white under parts.

**Charadrius dominicus fulvus** Gmelin. Pacific Golden Plover.

Small flocks were observed on the mud flats and sandy stretches of Kashvik Bay. One specimen was taken August 24.

**Arenaria melanocephala** (Vigors). Black Turnstone.

This species first appeared along the shores of Kashvik Bay about the first of August, and increased in numbers later. August 25, flocks of a hundred or more were seen and at this time it was one of the most abundant shore birds in the locality. They are attractive birds and I enjoyed watching large flocks of them very much. Specimens taken show some variation in color and bear dates ranging from August 7 to 21.

**Lagopus lagopus albus** (Gmelin). Willow Ptarmigan.

Small flocks of this game bird were seen occasionally on the tundra in August feeding on berries. Earlier in the season adults and young were observed on the mountain sides. The species is known to be decreasing in numbers in many sections, because it is not well adapted for protecting itself against its enemies. Specimens that we saw made no great effort to get away and usually could have been taken without much trouble on our part. Specimens taken August 28.

**Lagopus rupestris nelsoni** Stejneger. Nelson's Ptarmigan.

The only specimen seen was taken on the mountain side just back from Kashvik Bay, August 23. It does not appear to be a common species in that section.

**Falco columbarius** Linnæus. Pigeon Hawk.

Commonly seen during the summer. One one occasion a magpie alighted near our tent in a much excited condition. Hearing it we undertook to determine the cause and soon saw a pigeon hawk perched in a tree only a short distance away. We shot the hawk and made a skin of it and it bears the date of July 25. A few days later what we considered two adults and four young of the season were observed on the wing circling above our heads on the south side of Katmai Bay. On the

Willow Ptarmigan above, fall plumage; Western Savanna Sparrow at right; Alaska Longspur at left.

15th of August on Kubugalki Peninsula, I picked up a pigeon hawk that had been in an encounter with magpies. The hawk received such severe treatment that it was unable to fly away and it allowed me to walk up to it. The single magpie which was engaging the hawk when I first realized that a fight was on flew gracefully away on my approach to join six others of its kind which, very likely, had been helping in a common attack upon their enemy.

**Pica pica hudsonia** (Sabine). Magpie.

The magpie is rather plentiful in the wooded areas of the region visited. They are mostly seen in small flocks of five to eight and there is evidence that they adopt this method for protection against their natural enemies. On various occasions these birds demonstrated that they had no great fear of man, for more than once I have seen them fly towards me and alight just a few feet away. From observation it is evident that the pigeon hawk, which is plentiful, is one of their much dreaded enemies, and not being able to find adequate protection from it in such a wild and uninhabited country they often engage it in combat to the finish.

**Acanthis linaria** (Linnæus). Redpoll.

This was one of the most attractive of the smaller birds seen in Alaska. Flocks of them began to appear about camp near the middle of July and soon they were everywhere, in the lowlands, on the mountains, in the wooded areas, along the streams and on one occasion I saw a large flock flying merrily about over the Valley of ten thousand Smokes. They appeared to be just as well satisfied one place as another and the wind and rain and the steam and unpleasant odors of the "Valley," so far as I could observe, detracted nothing from the pleasures they gave evidence of enjoying wherever they happened to be. During my stay in the Valley they were the only birds seen that gave any indication at all of being attracted by the unique conditions and unusual scenery to be observed. Whenever Redpolls are within hearing distance, whether on the wing or perched in the bushes, they are giving continually their soft twittering notes by which they are recognized readily. There is always an attractiveness about these notes that gives one a pressing invitation to go and see the birds. Specimens were taken on July 23.

**Calcarus lapponicus alascensis** Ridgeway. Alsaka Longspur.

During the nesting season the males of this species especially are very attractive both from the standpoint of their song and coloration. Nesting birds are plentiful on the tundra areas during the summer and as the plants in such situations seldom grow tall enough to hide even a small bird they appear regularly in full view perched on a slight elevation, often only a few feet away where they may be studied to the heart's content. It is splendid indeed to hear the beautiful song of the male and have him sitting where his every movement may be observed and his intense enthusiasm may be realized. As fall approaches, males, females and young of the season all seem to appear in modest plumage and associate in flocks and feed on the various low-growing berries and seeds of the region. In crossing the tundra at this sesaon one hears their characteristic peeps, often close at hand, but usually does not see the birds until they fly up only a few feet away and arise high into the air and flit beyond the vision. Specimens in nesting plumage taken July 12. Other specimens August 15.

**Passerculus sandwichensis alaudinus** Bonaparte. Western Savannah Sparrow.

One of the characteristic birds of the base of the Alaska Peninsula. Abundant in all favorable places and it seemed to prefer the grass covered areas adjacent to the coast and spent most of the time either on or close to the ground. They have a rather low note which one hears continually when in the vicinity of their haunts. The species was usually at its best toward evening when they were feeding. Although the species was common about the vicinity of camp it did not come around the tents as some of the other sparrows did. Specimens were taken June 22 and July 8.

**Zonotrichia coronata** (Pallas). Golden-crowned Sparrow.

The song of the Golden-crowned sparrow was very familiar about base camp as well as over much of the Alaskan territory visited. We found the nest often placed near a tuft of grass or in the midst of a bunch of dwarf willows. It is located and constructed much like the nest of our common song sparrow. Several pairs had nests near our tent and soon learned to depend upon crumbs from our table for food supply. Some specimens

became so tame that they hopped about under the stools on which we were sitting and took pieces of bread which we dropped for them, or they alighted on the table and picked up crumbs about our plates and occasionally perched on our shoulders. Finally the young were old enough to leave the nest and came with their parents but would stand and squawk until the latter came with food. They developed rapidly and finally were able to come alone and soon learned to visit our store room and help themselves. As they became more and more meddlesome we tried to bar them from the tent but we did not succeed very well for they were quite handy in finding small openings that we overlooked. Up to the time we left they were making regular visits to our supplies and we found them to be much earlier risers than we were. I have often wondered what they did after we came away. The old ones ceased to come about regularly after the young were able to care for themselves and for a time we did not understand the reason, but one day we saw them looking very much tattered and worn. Molting time had come and apparently they were in partial hiding for their new plumage to develop. Specimen taken August 15.

**Melospiza melodia insignis** Baird. Bischoff's Song Sparrow.

A very common species inhabiting the rocky coast of Kadiac Island. Its chirp is much like that of our common song sparrow of eastern United States. It interested me especially because of its abundance and because it is much like a song sparrow we studied from the Katmai Bay region. Specimen taken September 12.

**Melospiza melodia sanaka** McGregor. Aleutian Song Sparrow.

A few specimens observed along the rocky coast of Katmai Bay. It is not quite so dark colored as the last but otherwise is much like that subspecies. Both are larger than the song sparrow we know in Ohio and both have longer and slenderer bills. Specimen taken July 25.

**Passerella illiaca unalaskensis** (Gmelin). Shumagin Fox Sparrow.

We found these birds in the margins of wooded areas and specimens came to our tent on various occasions to pick up crumbs for food. They were very quiet and retiring in habits,

although they did not show particular fear. One or two specimens became quite tame and gave us an opportunity to study them closely. They were of more than ordinary interest on account of their shyness. One specimen taken July 9.

**Dendroica æstiva rubiginosa** (Pallas). Alaska Yellow Warbler.

We did not see a great many warblers in Alaska, although we did not procure all the species we observed. This one was often seen in the wooded areas near camp on Katmai Bay, and it most likely nested but the nest was not found. Specimen taken July 12.

**Wilsonia pusilla piliolata** (Pallas). Piliolated Warbler.

This was the most plentiful warbler of the locality. Many pairs were seen in the wooded areas near base camp, and there was every indication that they were nesting although the nest was not observed. Specimens taken July 12 and 23.

**Anthus spinoletta rubescens** (Tunstall.) Pipit.

Not noted until about the first of August when many specimens were observed on the dry sandy beaches that occurred in places along Katmai and Kashvik Bays. The species continued to be common during the remainder of our stay in the locality and I became much interested in observing it as we came and went about our daily affairs. It has a characteristic note which it gives regularly and which makes its determination easy for one who learns to know it. Specimens taken August 10.

**Penthestes atricapillus turneri** (Ridgeway). Yukon Chickadee.

Flocks of this species appeared in the wooded areas about base camp just before the middle of July. It reminds one much of the Chickadee of Ohio and I felt that I was within hearing distance of an old acquaintance when I first heard its notes. The birds were molting in July and many of them appeared much worn. Specimens were taken July 12.

**Hylocichla guttata** (Pallas) Alaska Hermit Thrush.

We did not observe this bird often and do not consider that it was common in the region. A specimen was taken July 25, at the extreme east end of Katmai Bay in a very wild locality where evidences of bears and wild animal life were abundant. I take it that the species nested here although the nest was not observed.

# INDEX.

Citations marked with an asterisk (*) refer to illustrations.

H



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K



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M